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IMPACTS OF ECONOMIC GROWTH WITH FOREST PRESERVATION IN THE AMAZON AND CERRADO BIOMES IN BRAZIL

GÉSSICA C. P. SOUZA[*,‡], EDSON PAULO DOMINGUES[†]
and ALINE MAGALHÃES[†]

[*]*Federal University of Minas Gerais (UFMG)*
Avenida Presidente Antônio Carlos, 6627 Pampulha
Belo Horizonte, MG 31270-901, Brazil

[†]*Department of Economic Sciences*
Federal University of Minas Gerais (UFMG)
Avenida Presidente Antônio Carlos
6627 Pampulha, Belo Horizonte, MG 31270-901, Brazil
[‡]*gessicacps@yahoo.com.br*

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Brazil is a major agricultural producer and exporter, with agribusiness accounting for 26.6% of the country's gross domestic product (GDP). The growth of agriculture is the result of increased agricultural productivity and expansion over native vegetation. Deforestation causes direct and indirect changes in land use and increases in gross greenhouse gas (GHG) emissions. Brazil has ambitious GHG mitigation and deforestation reduction goals, facing a possible tradeoff between environmental conservation and economic growth. The main objective of this research was to analyze the economic and environmental impacts of "Green Growth" scenarios in the main Brazilian biomes. The model built and used for this analysis, the Brazilian Biomes, Land Use and Emissions Economic Model (BLUME), brings important methodological advances for integrated economic modeling with environmental aspects in Brazil. The results indicate that simulated policies would be able to avoid part of national emissions at a relatively small cost compared to national GDP.

Keywords: Climate change; mitigation and adaptation models; fair transition.

1. Introduction

Brazil is a major producer and exporter of agricultural products. Agriculture and livestock accounted for 26.6% of the country's gross domestic product (GDP) in 2020, with soybeans (grains, bran, and oil) accounting for 40% of national exports and meat responsible for 14% (Fao *et al.*, 2021). Soybean cultivation alone showed a growth of

[‡]Corresponding author.

AQ: Fao et al. (2021) is not listed in the reference list. Please delete the citation of unlisted reference from text.

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27 Mha in the planted area between 1988 and 2020, and pasture areas grew 850% from 1994 to 2016.

The expansion of agriculture and livestock is occurring in the face of increased productivity and reduction of native vegetation. According to Gasques *et al.* (2019), land productivity in Brazil grew 3.4% from 1975 to 2018. According to Souza *et al.* (2020a), in 33 years, the country has lost 102.4 Mha of natural vegetation, mainly for livestock and agricultural activities, which is equivalent to an average of 3.1 Mha per year. The greatest pressure on the original soil cover has occurred in the Amazon and Cerrado biomes, which together have 75.6% of the deforested areas from 1985 to 2017.

The expansion of agriculture and livestock, which cause direct and indirect changes in land use, has been the main factor of deforestation in Brazil, directly affecting the environment and vegetation cover. There are also indirect factors, associated with the growth of markets, such as the development of infrastructure and cities (Souza *et al.*, 2020a); the increase in population density (Igliori, 2006); insecurity about land ownership rights (Araújo *et al.*, 2009); fiscal and credit policies to encourage the expansion of the agricultural frontier (Walker *et al.*, 2000), among others.

The cumulative effect of this increase in deforestation, in turn, has contributed to global climate change (World Bank, 2021). In Brazil alone, gross greenhouse[1] gas (GHG) emissions increased by 17% between 1990 and 2019, and almost 10% between 2018 and 2019, with the land use and land cover change sector being the highest emission activity, with an increase of 23% between 2018 and 2019 (Albuquerque *et al.*, 2020). The scenarios projected for Brazil by the Brazilian Panel on Climate Change (PBMC, 2014a) suggest that, without mitigation policies, an increase in the extreme events of droughts and prolonged droughts is expected, especially in the Amazon, Cerrado and Caatinga biomes, with such changes intensifying from the middle and end of the 21st century.

The economic and social problems of these climate changes would be significant, with impacts on agriculture (Domingues *et al.*, 2011; Faria, 2012; Moraes, 2010), food insecurity (Bateman *et al.*, 2013; Gazzoni, 2014; Lapola *et al.*, 2010; Turner *et al.*, 2007), health (Rosenberg *et al.*, 2000; Schultz *et al.*, 2003), social welfare (Tanure, 2020), migration (Barbieri *et al.*, 2010; Ferreira Filho and Horridge, 2010), among others.

Given the adverse impacts of climate change, Brazil pledged in 2015, at COP 21, to reduce GHG emissions by 37% by 2025 and by 43% by 2030, compared to 2005 levels. The proposal is to eliminate illegal deforestation by 2030 and promote the recovery of 12 Mha of native vegetation in the biomes. The objective is to reduce greenhouse gas emissions by 37% by 2025 and 43% by 2030, compared to 2005 levels (INDC, 2015).

[1]In gross emissions, CO_2 removals from the atmosphere are not discounted due to changes in land use (for example, the growth of secondary forests instead of pastures) and the maintenance of forests in indigenous areas and protected areas. Therefore, gross emissions are always higher than net emissions.

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Like other developing countries, Brazil faces the triple challenge of reducing GHG emissions, reducing deforestation and promoting economic growth. Much is discussed in the literature about whether it is necessary to deforest for economic growth and how much land productivity should be increased to compensate for the economic losses of a land restriction policy. Just as relevant as these issues are measuring the investment needed to increase productivity (of land and capital) that offsets the restriction on the expansion of land use. In this sense, this research proposes to evaluate the economic and environmental impacts of zero deforestation in the Amazon and Cerrado biome, to measure the economic costs of this policy and the necessary investments in land-intensive sectors that offset these costs. In this way, it will be possible to analyze the impacts of a "Green Growth" scenario in the Amazon and Cerrado, based on the implementation of a zero-deforestation policy combined with sectoral investments.

The model built and used for this analysis, BLUME, brings important methodological advances for integrated economic modeling with environmental aspects in Brazil. Its regionalization allows to capture regional differences in climate, geomorphological and regulatory issues. In addition to considering the direct and indirect changes in land use — land use change (LUC) and indirect land use change (ILUC) — and emissions not only associated with the land use change sector but also other emission sectors, such as energy and industries.

The following section presents the research methodology, addressing the main aspects of the BLUME model and its advances in terms of regionalization, land use module and emissions module. In Sec. 3, we find the simulations and main results and, finally, in Sec. 4, we present the final considerations.

2. Methodology

The link between economics, changes in land use and GHG emissions is complex and involves branches of interdisciplinary studies. There are several challenges to research given that the causes and consequences of climate change are global and that there is a great economic and environmental heterogeneity between regions. The development of models capable of integrating environmental and economic issues in a regional way are recent challenge in the literature and is summarized in three aspects: econometric models (Gouvello *et al.*, 2010; Kerr *et al.*, 2003; Plantinga and Mauldin, 2001; Stavins, 1999), partial equilibrium models (Havlík *et al.*, 2011; Sands and Kim, 2008) and general equilibrium models (Ferreira Filho and Horridge, 2014; Hertel *et al.*, 2008; Paltsev *et al.*, 2005, among others).

The computable general equilibrium (CGE) models are capable of dealing with policy shocks and answering complex and real questions of the economy, involving several agents and sectors. In this type of modeling, the sectors are interrelated and the productive structure of economies or regions are treated explicitly. In analyses that involve land use change, the CGE models systematically capture the effects of land use

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transitions in addition to being able to incorporate the behavior of producers in relation to land demand. Therefore, this type of modeling is suitable for the analysis of mitigation and adaptation policies, agricultural expansion policies, among other issues involving soil changes and climate change.

BLUME, a model built for the simulations of this research, is an instrument of general interregional computable equilibrium with recursive dynamics, developed for analysis of the Brazilian economy and its regions. It follows the theoretical framework of the regional The Enormous Regional Model (TERM) developed by the Centre of Policy Studies (CoPS) of Australia (Horridge *et al.*, 2005). The results reported herein were obtained using the economic modeling software GEMPACK (Horridge *et al.*, 2019).

The BLUME database was built through a regionalization procedure using the national BRIDGE model as a structure (Domingues *et al.*, 2010) and other models developed at the Centro de Desenvolvimento e Planejamento Regional da Universidade Federal de Minas Gerais (Cedeplar-UFMG) such as IMAGEM-B (Domingues *et al.*, 2009), REGIA (Carvalho, 2014) and BBGEM (Souza, 2020). BLUME's base year is 2015 and has as one of the main differentials interconnected land use and emissions modules, allowing the analysis of the environmental impact of policies involving direct and indirect land use changes, known in the literature as *Land Use Change* (LUC) and *Indirect Land Use Change* (ILUC). BLUME goes beyond the anthropogenic emissions of land use and change, it concomitantly represents the emissions of all emitting sectors: land use, land-use change and forestry (LULUCF), industry, agriculture and energy activities. The regionalization adopted is also unprecedented in the literature, being the economic and environmental model with the largest regional breakdown developed so far for Brazil.

The regionalization of BLUME has a well-defined cut of Brazilian biomes, along with their states, making it possible to capture a certain spatial heterogeneity and geomorphological characteristics, in the same way as the AEZs developed by GTAP (Lee, 2004). Although within the same biome there are significant differences in terms of soil conditions, climate and human interference, for example, the regionalization adopted already demarcates geomorphological differences and regulatory issues important for the analysis.[2] In these terms, BLUME has 48 regions built according to the six Brazilian biomes — Mata Atlântica, Caatinga, Cerrado, Pampa, Pantanal and Amazonia — and the 27 states of the federation, according to the map in Fig. 1. This regionalization is one of the main methodological contributions of BLUME due to the lack of environmental CGE models with such a level of regional disaggregation.

The sectoral disaggregation of the model database prioritized the agricultural sectors, which are directly related and impacted by policies of direct and indirect land use changes. Thus, BLUME has 52 sectors in its structure, 14 consisting of agricultural

[2] A disaggregation considering more specific geomorphological issues would require georeferenced pedological and climatic data, making it difficult to reconcile with economic data whose lowest level of disaggregation is municipal.

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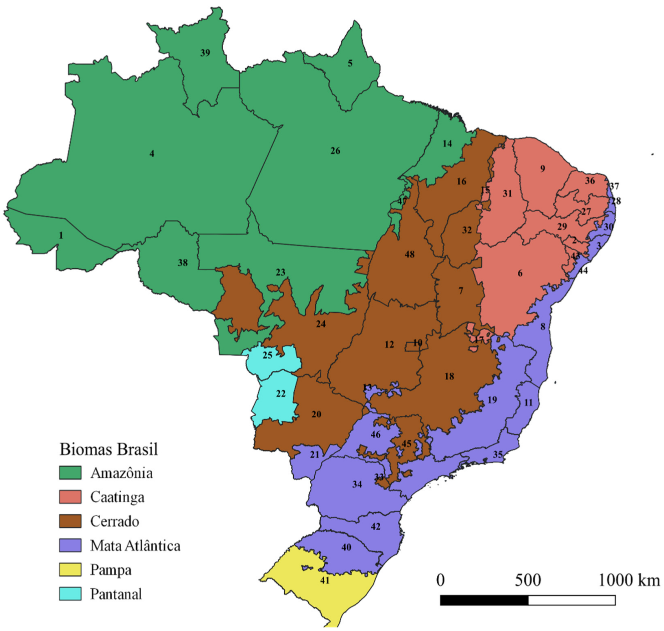

	Região	Estado
1	AC_Amazonia	Acre
2	AL_Caatinga	Alagoas
3	AL_Mata Atlant.	Alagoas
4	AM_Amazonia	Amazonas
5	AP_Amazonia	Amapá
6	BA_Caatinga	Bahia
7	BA_Cerrado	Bahia
8	BA_Mata Atlant.	Bahia
9	CE_Caatinga	Ceará
10	DF_Cerrado	Destrito Federal
11	ES_Mata Atlant.	Espírito Santo
12	GO_Cerrado	Goiás
13	GO_Mata Atlant.	Goias
14	MA_Amazonia	Maranhão
15	MA_Caatinga	Maranhão
16	MA_Cerrado	Maranhão
17	MG_Caatinga	Minas Gerais
18	MG_Cerrado	Minas Gerais
19	MG_Mata Atlant.	Minas Gerais
20	MS_Cerrado	Mato Grosso do Sul
21	MS_Mata Atlant.	Mato Grosso do Sul
22	MS_Pantanal	Mato Grosso do Sul
23	MT_Amazonia	Mato Grosso
24	MT_Cerrado	Mato Grosso
25	MT_Pantanal	Mato Grosso
26	PA_Amazonia	Pará
27	PB_Caatinga	Paraíba
28	PB_Mata Atlant.	Paraíba
29	PE_Caatinga	Pernambuco
30	PE_Mata Atlant.	Pernambuco
31	PI_Caatinga	Piauí
32	PI_Cerrado	Piauí
33	PR_Cerrado	Paraná
34	PR_Mata Atlant.	Paraná
35	RJ_Mata Atlant.	Rio de Janeiro
36	RN_Caatinga	Rio Grande do Norte
37	RN_Mata Atlant.	Rio Grande do Norte
38	RO_Amazonia	Rondônia
39	RR_Amazonia	Roraima
40	RS_Mata Atlant.	Rio Grande do Sul
41	RS_Pampa	Rio Grande do Sul
42	SC_Mata Atlant.	Santa Catarina
43	SE_Caatinga	Sergipe
44	SE_Mata Atlant.	Sergipe
45	SP_Cerrado	São Paulo
46	SP_Mata Atlant.	São Paulo
47	TO_Amazonia	Tocantins
48	TO_Cerrado	Tocantins

Source: Own preparation.

Figure 1. Regions of the blume model.

activities, 7 of livestock activities and 2 related to forestry and plant extraction as reported in Chart 1.

2.1. *The land use module*

The construction of the land use module followed the theoretical structure of the REGIA model (Carvalho, 2014) whose land is considered one of the primary factors, as well as capital and labor. The primary factor land is used in the production of the agricultural, forestry and livestock sectors and its use is modeled separately for each of the regions, keeping the total area fixed.

Four types of land use were considered, namely: Cropland, pasture, planted forest and natural forest and other uses, in each one a distinct sectorial production was

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Sectors			
1	Rice	27	Pork products
2	Wheat and other cereals	28	Poultry meat
3	Grain corn	29	Industrial fishing
4	Cotton and other fibers	30	Cooled/pasteurized milk
5	Sugarcane	31	Other dairy products
6	Soybean grain	32	Animal feed
7	Cassava	33	Food and beverage
8	Leaf tobacco	34	Clothing and textiles
9	Citrus fruits	35	Footwear and leather
10	Beans in grain	36	Wood product
11	Other temporary	37	Pulp
12	Orange	38	Miscellaneous industry
13	Coffee grain	39	Ethanol and biofuel
14	Others Permanent	40	Chemicals
15	Cattle	41	Manure and fertilizer
16	Other animals	42	Pesticide and disinfectant
17	Cow's milk	43	Electronics
18	Milk from other animals	44	Automotive machinery and equipment
19	Pigs	45	Services
20	Poultry	46	Electricity, gas, and others
21	Eggs	47	Construction
22	Forestry	48	Trade, wholesale, and retail
23	Plant extraction	49	Cargo transportation
24	Agricultural fisheries	50	Transportation of others
25	Extractive industry	51	Financial institution and insurance
26	Beef and other animals	52	Public sector

Source: Own preparation based on the sectors of the BLUME model.

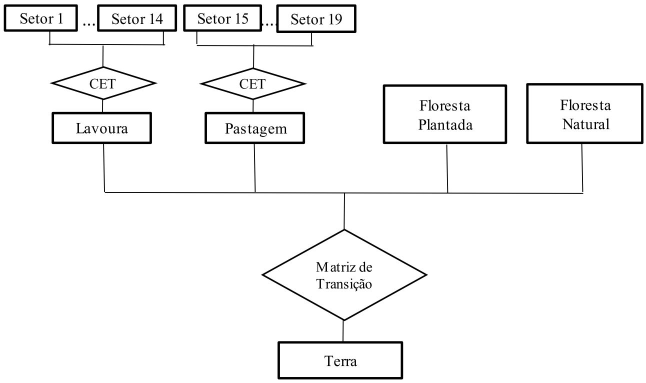
Chart 1. BLUME model database sectors.

attributed. The cropland areas are used in the production of the first 14 sectors of the model, which are strictly agricultural. In the pasture areas, the production of the five livestock sectors of the model is attributed. The planted forest areas are used by the forestry and plant extraction sectors. Finally, the areas of natural forest and other uses (lakes, cities, roads, etc.) remained, these are not associated with any sectorial production.

It is expected that the other uses areas will change more slowly than natural forests and, therefore, a variation in the land use category natural forest and other uses can be considered a proxy for the advance of deforestation caused by the expansion of agriculture or livestock. As in the REGIA model (Carvalho, 2016), in BLUME the land process is guided by two levels of substitution, as shown in Fig. 2.

At the first level, agricultural land and pastures can be allocated between different agricultural sectors according to the difference in remuneration.[3] Thus, the demand for land responds to changes in the land remuneration of each sector. At this level, each land use (cropland, pasture, and planted forest) is distributed in year t according to a constant elasticity transformation (CET) function between different products for each region. In the second level we have the structure of the land supply according to the different uses representing the dynamic adjustment in the land market. This structure allows the earth factor to move between the different earth categories between year t

[3]The remuneration of the land factor (V1LND) in the BLUME model was extracted from the account "expenses incurred by the establishments: land lease" of the Agricultural Census of 2018 and referring to the year 2017. Its value was deflated for the year 2015 in order to match the data of MIP 2015.



Source: Own preparation based on Carvalho (2014).

Figure 2. Allocation of the land factor in the BLUME model.

and year $t + 1$. For this, the conversion process is controlled by means of a transition matrix that represents the possibilities of land conversion between year t and year $t + 1$. The matrix represents the mobility of the land between uses, indicating the possibilities of transformation of the different uses of the land.

The transition matrix captures the fact that more productive land is initially used in the production process and, at the same time, the marginal use of land that could be converted into productive use is limited. The economic process of land conversion occurs as follows: the forests would initially be converted into pasture areas, which after some time would be able to be converted into cropland areas (Cattaneo, 2001; Ferreira Filho and Horridge, 2012; Macedo *et al.*, 2012).

Therefore, the matrix shows that conversion between uses, for example, between pasture and cropland is easier to perform than between deforested forests to cropland directly. If the difference between the amount of land used in agricultural production and the total area of the region is large, then increases in demand for land will lead to greater land conversion for agricultural use. This, in turn, will lead to an increase in land remuneration to offset the costs associated with this conversion.

The land use transition matrix of the BLUME model was extracted from the MapBiomas platform (Souza *et al.*, 2020b)[4,5] that provides data not only on land cover and use in Brazilian municipalities, but also the annual transition information between 1985 and 2019. Thus, it was possible to aggregate the municipal information and build the transition matrices of the 48 regions of the BLUME model. MapBiomas data have four levels of soil classification. For this research, classification level 2 was used, which is consistent with the classes of the IV National Inventory of Emissions and

[4]https://plataforma.brasil.mapbiomas.org/.

[5]In MapBiomas Collection 5, class transitions represent both effective land use changes and classification inconsistencies. Therefore, they may not be a completely faithful representation of changes in land use in the period. Sums of the total areas of each transition table class may have minor changes from coverage data for the same year due to the filter applied to the transition maps.

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Table 1. Land use transition matrix between 2010 versus 2016 of Brazil (millions of hectares).

Brazil	Cropland	Pasture	Planted forest	Natural forest and other uses	Total 2010
Cropland	54.1	6.3	0.3	3.8	64.5
Pasture	14.1	154.7	0.8	12.6	182.2
Planted forest	0.0	0.0	6.4	0.2	6.6
Natural forest and other uses	5.9	20.1	0.9	571.9	598.7
Total 2016	74.1	181.1	8.3	588.4	852.0

Source: Own elaboration based on municipal data from the MapBiomas platform (Souza *et al.*, 2020b).

Anthropic Removals of Greenhouse Gases. It was decided to make the model compatible with this classification level since the emission matrix will be built based on data from the IV Inventory, which justifies the need to make the classes compatible (more details regarding the compatibility of the classes are found at Souza, 2022).

Table 1 shows the transition matrix of land use that feeds the base year of BLUME to Brazil. The totals of the rows and columns reflect the land use in the years 2010 and 2016 and the interior of the matrix shows the transition between the different land uses in the analyzed period. According to the data, 14.1 Mha of Pasture were converted into cropland between 2010 and 2016 and 20.1 Mha of natural forest became pasture. There is also a significant area of pasture converted into natural forest, about 12.6 Mha, which is consistent with the reforestation policies implemented in this period.

2.2. *The emissions module*

The BLUME model also captures GHG emissions from changes in land use and other polluting sources such as the use of fossil fuels and industrial processes. Thanks to the regionalization adopted, it is possible to control the heterogeneity of emissions from land use transition processes, which are quite different among Brazilian biomes. For example, the conversion of forest areas into pastures releases more carbon dioxide in the Amazon than in the Cerrado biome. This heterogeneity is captured in the model. The construction of the emissions module followed, in general, the procedure adopted by Silva (2015) and the theoretical specification of the BeGreen model (Magalhães, 2013).

To capture emissions from land use changes, emission matrices were associated with the land transition matrix. The emission matrices were constructed and regionalized based on data from the IV National Inventory (MCTI, 2020).[6] The LULUCF sector report presents the estimates of anthropogenic emissions by sources and removals by sinks associated with the LULUCF sector, for the period from 1990 to 2016 and for the five Brazilian biomes.

[6]Public consultation with experts' version published in May 2020.

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Table 2. Net emission matrix of the land use transition between 2010 versus 2016 of Brazil (Gg of CO_2eq).

Brazil	Cropland	Pasture	Forest planted	Natural forest and other uses	Total 2010
Cropland	0	13.600	−23.645	4.632	−5.414
Pasture	277.741	16,518	−192.852	21.522	122.928
Planted forest	24.386	67.235	7,864	−20.677	78.808
Natural forest and other uses	518.014	3,178,506	66.835	−1,984,862	1,778,493
Total 2016	820.141	3,275,859	−141.798	−1,979,385	1,974,816

Source: Own elaboration based on data from the IV National Inventory (MCTI, 2020).

To make these data compatible with the 48 regions of the BLUME model, a regionalization via shares was adopted, that is, the participation of the land use transition of each region on the transition of its respective biome was calculated. This share was used to calculate the total emissions of this region. Table 2 shows the net emissions from land use change between 2010 and 2016 in Brazil. In the period, the country emitted 1,974,816 Gg of CO_2eq, which is equivalent to 282,117 Gg of CO_2eq annually.[7] It is observed that the transition from natural forest to pasture is the largest emitter, with 3,178,506 Gg of CO_2eq, or 454,072 Gg of CO_2eq *per* year.

The BLUME model goes beyond the anthropogenic emissions of land use and change. The model also captures emissions from sectoral activities and fuel use. This is a great differential compared to other Brazilian models. For the incorporation of these emissions, BeGreen (Magalhães, 2013) was used as a reference, a model developed for the analysis of GHG reduction policies in the Brazilian economy.

Emissions derived from fuels (energy) and economic activity (industrial and agricultural) were obtained from the Greenhouse Gas Emissions and Removal Estimates System (SEEG). The SEEG is an initiative of the Climate Observatory that comprises the production of annual estimates of greenhouse gas emissions in Brazil.[8] For this research, it was decided to aggregate the emissions from industrial and agricultural activities, calling them only emissions from activities. The three emission sources considered in the BLUME, energy, activity and change of land use model total 1,148,534 Gg CO_2eq, according to Table 3. Recalling that here are represented the net emissions of the LULUCF sector. Energy and activity alone account for 80% of emissions, i.e., 1,136,417 GgCO_2eq. Of these emissions, 95% are domestic.

The emission in the use of fuels is modeled as directly proportional to its use, as well as the activity emissions in relation to the product of the related industries.

[7]The IV Inventory reports the net emissions, which are the metric adopted by the Federal Government. In net emissions, removals are already discounted, so they correspond to the final emissions. For this thesis, emissions from land use change are net, as well as in the IV Inventory.

[8]See: https://seeg.eco.br/. Accessed on 1 October 2021. The SEEG emissions are compatible with the methodology adopted by both the IPCC and the Brazilian Emissions Inventory.

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Table 3. Emissions according to the emission sources of the BLUME model (2015) (Gg CO_2eq).

Emission sources	Domestic	Imported	Total
Energy	377.956	53.541	431.497
Activity	704.918	0	704.918
LULUCF	282.117	0	282.117
Total	1,364,992	53.541	1,418,534

Source: Own elaboration based on SEEG data.

There are no endogenous technological innovations in the model for the use of fossil fuels, which, for example, allow the burning of coal to release less CO_2 *per* ton used. Sectors, on the other hand, can reduce their emissions by replacing energy inputs, via relative price changes.

The emissions associated with the productive process of the sectors are characterized by not being associated with the use of fossil fuels, but with the productive activity directly. For example, methane emissions from herds are classified as emissions by the productive process of the livestock sector, which in the case of the BLUME model, corresponds to the bovine sector.

3. Simulations and Results

3.1. *Reference scenario*

The reference scenario of BLUME simulates a trend of growth of the Brazilian economy. This scenario makes it possible to visualize the different trajectories of economic indicators over time and the impact of policy shocks on this trajectory. The difference between the reference scenario and the policy scenario represents the effect of the imposition of the zero-deforestation policy. The results of the model are normally presented as the accumulated deviation of a given variable (indicator) from its accumulated value in the reference scenario.

The first economic growth scenario updates the data observed from 2015 to 2020, namely national macroeconomic data, deforestation rates, and sectoral exports' rate. The observed variations in real GDP, household consumption, government spending, investment and export are taken from the national accounts published by the Brazilian Institute of Geography and Statistics IBGE. The observed data on the increase in deforestation were taken from the TerraBrasilis platform of National Institute for Space Research (INPE)[9] and from the official reports of the SOS Mata Atlântica institute.[10] Sector exports, on the other hand, follow the data from Ministry of Agriculture,

[9]See: http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates. Accessed on August 2021.
[10]See: https://www.sosma.org.br/noticias/desmatamento-da-mata-atlantica-cresce-quase-60-em-um-ano/. Accessed on August 2021.

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Livestock and Food Supply (MAPA, 2019) and Organization for Economic Co-operation and Development OECD (2015).[11]

From 2021 to 2040, the projections of growth of macroeconomic variables, sectorial exports and population growth are considered, the latter two varying by region of the model. Macroeconomic aggregates grow 2% p.a., sectorial exports evolve additionally according to (MAPA, 2019) and OECD (2015) projections and the population grows according to IBGE projection estimates.[12] It is important to incorporate export growth projections since agricultural products are considered an important determinant of deforestation in the Amazon and Cerrado biomes, in addition to being important in the dynamics of the Brazilian economy. Throughout the period, it is considered an increase of 1% p.a. in land productivity and 0.8% p.a. in labor productivity. In the projections, deforestation becomes endogenous, determined by the growth of the economy according to the BLUME land use mechanisms.

Graph 1 shows the trajectory of the main macroeconomic variables over the period from 2016 to 2040. It is noted that between 2016 and 2020 the economic indicators present a greater volatility, as they illustrate the real behavior observed in the economy. During this period, there was a drop in investment of −9.3% and real GDP of −3.6%, so capital levels also decreased, raising rates of return in the economy. With higher rates of return, investment increases in subsequent periods and promotes new pressure on the rate of return on capital, which tends to fall and remain stable over the long term and fluctuates around the GDP growth rate. In short, aggregate investment goes through a period of growth between 2021 and 2035, which is explained by the capital accumulation mechanisms of the BLUME model. Between 2021 and 2040, household consumption, government spending, aggregate employment, and real GDP show growth trajectories of 2% p.a. Aggregate employment follows the same trajectory of GDP growth.

Graph 2 shows the trajectory over time of the amount of land used in each category of use of the model (cropland, pasture, planted forest, and natural forest) for Brazil. The total land area must remain fixed, that is, the sum of the uses of each category must total the total area of Brazil or region of the model. Therefore, the growth of a given land use would imply the reduction of one or more uses. In the case of the reference scenario, the growth of the areas of cropland, pasture, and planted forest would happen to the detriment of the reduction of natural forest.

The BLUME reference scenario projects an increase of 37.1 Mha of Pasture between 2021 and 2040, this would be the category of land use with the most upward growth trajectory. The area of Cropland would show an increase of 17.4 Mha and the planted forest would show an almost constant growth, totaling 2.4 Mha by 2040.

[11]Database presented in the OECD-FAO Agricultural Outlook, published in July 2015, with agricultural projections until 2024. For most of the commodity sectors analyzed in Outlook, detailed supply and use values are available, as well as domestic and international commodity prices. Available at: https://stats.oecd.org/viewhtml.aspx?datasetcode=HIGH_AGLINK_2015&lang=en.

[12]See: https://www.ibge.gov.br/apps/populacao/projecao/.

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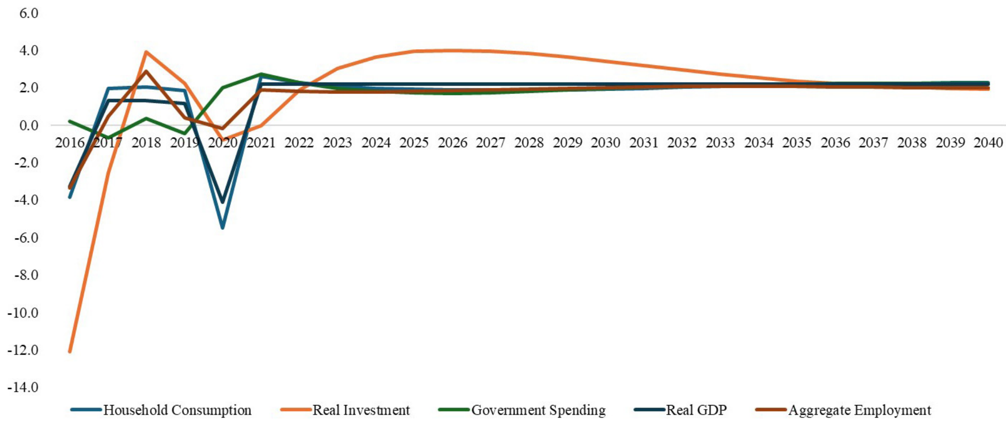
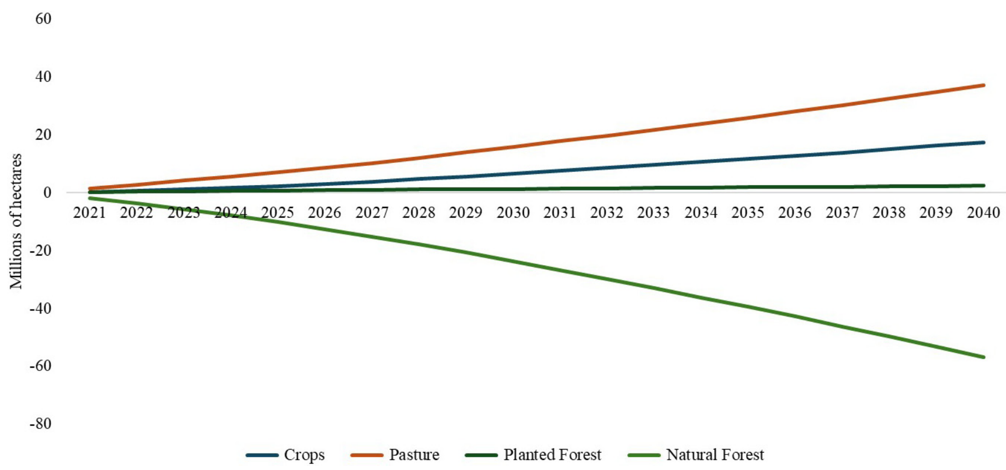


Source: Own preparation based on the results of the BLUME model.

Graph 1. Trajectory of national macroeconomic variables between 2016 and 2040 in the reference scenario.

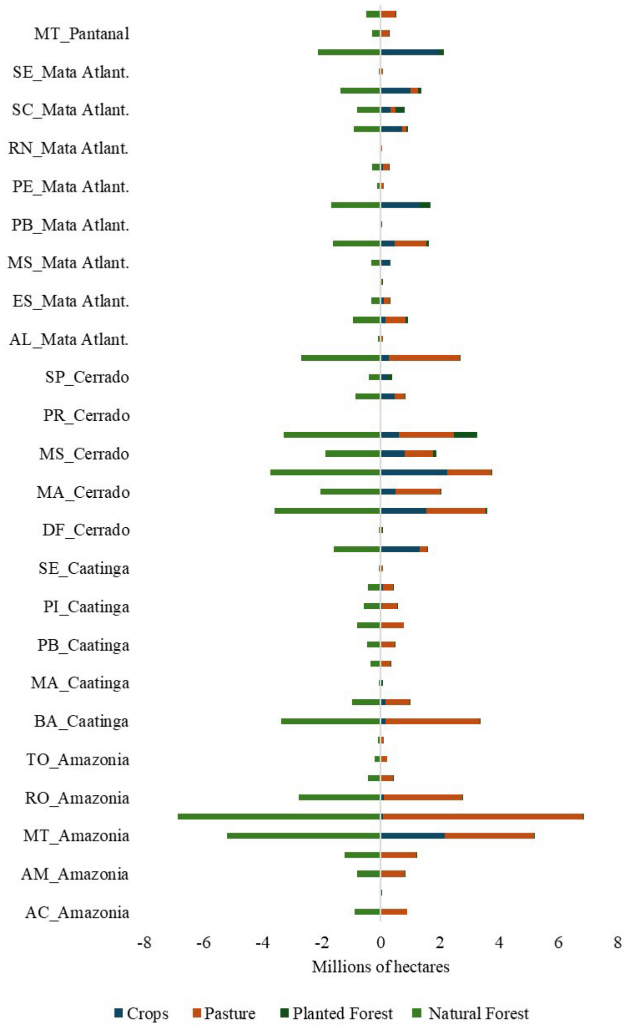
The natural forest area would have a downward trajectory throughout the period, but more markedly from 2027, totaling 57 Mha lost in 2040. This value would represent deforestation throughout Brazil in the period under analysis and would amount to an average of 2.8 Mha deforested annually.

The deforestation results of the reference scenario are interesting since the model projected an average annual deforestation of 2.8 Mha, above the average observed in the last 10 years (1.5 Mha), but according to a longer average of 33 years (3.1 Mha)



Source: Own preparation based on the simulation results with the BLUME model.

Graph 2. Projection of land use in the reference scenario for Brazil (millions of hectares).



Source: Own preparation based on the simulation results with the BLUME model.

Graph 3. Variation of the areas of cropland, pasture, planted forest, and natural forest in the reference scenario and regions of the BLUME model — accumulated 2021 to 2040 — (million hectares).

(Souza *et al.*, 2020a). This result is explained by the fact that the model does not limit the use of land available for conversion, as determined by Law 12.652/2012, art. 12. According to the law, the entire rural property must maintain an area with native vegetation coverage, as a legal reserve, observing a minimum percentage in relation to the area of the property. In the Legal Amazon region, this value is 80% of the property located in forest areas, 35% located in the Cerrado area and 20% in the Campos Gerais areas (Brazil, 2021). It was decided not to include these limitations in the model given the

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recent loosening of the Brazilian inspection regarding illegal deforestation. Thus, we are portraying an economic deforestation similar to times with little or no inspection.

The growth of the economy projected in the reference scenario would cause an increase in the use of production factors and consequently a variation in the remuneration of these factors. This would explain the greater use of pasture in the projection results of land use. An increase in the remuneration of pasture in relation to the remuneration of other land uses would lead to a process of conversion, mainly from natural forest areas to pasture areas.

Another determining factor in the results is the projections of increase in exports established at the closing of the model. In these projections, the growth in exports of cattle, sugarcane, soybeans, and other agricultural products would contribute to making pasture and cropland areas more advantageous, stimulating the conversion of forest for agricultural and livestock uses.

As seen in the section of the module of land use and emissions, the transition matrix would represent the possibilities of conversion between the uses and the direction of this conversion would occur basically from natural forest to pasture and from pasture to cropland. The possibilities of conversion of planted forest are more limited, therefore, for there to be a large conversion towards this type of use, it would be necessary to significantly increase its remuneration in relation to other uses, which clearly does not happen given the almost linear growth of this category.

The downward trajectory of the natural forest over time can be interpreted as an increase in the remuneration of other uses in relation to the remuneration of natural forest. The possibilities of this conversion are given by the transition matrix and the pre-established regional land supply elasticities. If a region has a larger area available for conversion, the greater the likelihood that land conversion will occur in that region. Thus, Graph 3 shows the results of land use variation in the regions of the model in the period from 2021 to 2040.

The MT_Cerrado region would have the largest expansion of the cropland areas, approximately 2.2 Mha more in 2040, clearly to the detriment of the natural forest areas. The growth of the cotton and temporary fibers and soy sectors are the ones that would contribute the most to this expansion. According to the descriptive analysis of the data, the MT_Cerrado region is responsible for 63.7% of the national production of cotton and temporary fibers and would present an accumulated growth of 90% by 2040. The region is also the largest producer of soybeans, with 17% of all national production, and 98% growth in the sector accumulated by 2040. Therefore, the low production costs and the increase in the remuneration of the land, make it more attractive to convert forest areas for the use of cropland in this region.

The region with the highest expansion of pasture would be PA_Amazônia, with 6.7 Mha more in 2040. This expansion was also clearly at the expense of forest areas and is justified by the growth of the bovine and milk sectors, both cow and other types. The region is the sixth largest producer of cattle and would show a growth of 78% in this sector. In addition to being the largest national producer of cow's milk and other

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milk together, about 22% of all national production. On average, these sectors would grow 56% in the accumulated until 2040.

The GO_Cerrado region is the largest national cattle producer and would show an increase in pasture of 2 Mha. This is justified by the higher productivity of the sector in this region and the availability of land for conversion, given by the transition matrix. Few regions would show a decrease in pasture areas, one of them is SP_Cerrado, a region with the highest national production of sugarcane. This justifies the low remuneration of pasture land and, consequently, the conversion of these areas into cropland.

In relation to the planted forest areas, we have the MG_Cerrado region with the highest growth, 0.8 Mha of additional areas in 2040. This region is the third largest producer of forestry, a sector that would show growth of 58% in the accumulated until 2040 in the region. PR_Mata Atlântica, the region with the highest national production of Forestry, would present the second largest growth of Planted Forest area, 0.4 Mha. In general, the growth of the Planted Forest areas would be lower than the other uses, since the remuneration of this type of use is relatively lower than the others. In addition, in the transition process, Planted Forest is the last category to be converted.

The regions with the largest deforested areas would consequently be those with the highest growth of the pasture and cropland areas, the latter intended mainly for the expansion of soybeans. Only the PA_Amazônia region would be responsible for 6.7 Mha less Natural Forest and MT_Amazônia for 5.2 Mha less. Both regions would present the largest increases in pasture area since they are important producers of the Bovine sector. In addition to the Pasture areas, the MT_Amazônia region would also significantly expand the Cropland areas to the detriment of the Soybean plantation, as well as the MT_Cerrado region, responsible for 3.7 Mha of deforested area.

These two regions of the state of Mato Grosso are the main producers of soybeans in Brazil. In these cases, the scenario points out that the expansion of livestock and soybean production would advance over the natural forest, in the form of deforestation. However, it is worth noting that it is not only the growth of these two sectors that implies forest conversion in the BLUME model. Other mechanisms are also important, such as intersectoral relations and foreign trade, which would also influence land conversion in the regions.

3.2. *"Green growth" scenario in the Amazon and Cerrado*

Accumulated deforestation in the Legal Amazon has been 45 Mha since 1988. Annual rates vary in cycles of greater and lesser intensity over the years, as observed in Graph 4 below is not appearing, it should be a graph with lines and bars called Increase in deforestation in the Legal Amazon, Amazon biome and Cerrado - 1988 to 2020 (Millions of Hectares). From 2004 to 2014, there was a decrease in the areas deforested annually.

However, from 2015 the values have been increasing progressively. From 2015 to 2020, 4.9 Mha were deforested in the Legal Amazon, with emphasis on the period between August 2019 and July 2020, with 1.1 Mha, a record of the last 12 years. Virtually all deforestation in the Legal Amazon takes place in the Amazon biome.

The Cerrado biome is the second largest biome in South America and represents almost 24% of the entire Brazilian territory. From 2008 to 2020, deforestation in this biome surpassed the lost areas of the Amazon biome, adding up to more than 12 Mha. Deforestation occurs cyclically. It is noted that in the years when the rate in the Amazon decreases, there is an increase in the lost areas of the Cerrado. Accelerated deforestation in the biome, combined with the high occurrence of anthropic fires, makes the Cerrado the biome with the highest volume of net emissions due to land use change in Brazil (MCTI, 2020). Deforestation in the Cerrado is more intense due to the environmental characteristics that make the region suitable for agriculture and livestock, in addition to the demand for charcoal, destined for the steel industry. The challenge of reconciling production growth with environmental protection is an eminent problem in the biome, in view of the great demand for occupation of land destined for agribusiness.

According to the IV National Inventory (MCTI, 2020), the relative contribution to net CO_2 emissions from land use and land cover change indicated that, between 2010 and 2016, land changes in the Cerrado accounted for 49% of emissions national CO_2 emissions, while relative contributions from changes in the Amazon biome accounted for 34%. These two biomes are the drivers of national emissions trends in the LULUCF sector, as together they represent about 73% of the Brazilian territory, with significant carbon stocks.

At the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), Brazil committed to reducing deforestation in the Amazon and Cerrado, in order to reduce Brazilian emissions. The Brazilian challenge is to eliminate illegal deforestation by 2030 and promote the recovery of 12 Mha of native vegetation in the biomes. The objective is to reduce greenhouse gas emissions by 37% by 2025 and 43% by 2030, compared to 2005 levels (INDC, 2015). With regard to the Cerrado biome, the target set is to reduce annual deforestation rates by 40% in relation to the average verified between 1999 and 2008. To this end, the Action Plan for Prevention and Control of Deforestation was created and Queimadas no Cerrado (PPCerrado), which aims to control deforestation and monitor the remaining areas of the biome and improve environmental inspection. However, the PPCerrado was extinguished in 2019 along with the Prevention and Control of Deforestation in the Amazon (PPCDAm) and replaced by a 19-page document, without goals, deadlines or indication of attributions or funding.

Much is discussed in the literature about whether it is necessary to deforest for economic growth and how much land productivity should be increased to compensate for the economic losses of a land restriction policy. Just as important as these issues is measuring the investment needed to increase productivity (of land and capital) that offsets the restriction on land use expansion. Thus, the policy simulations in this

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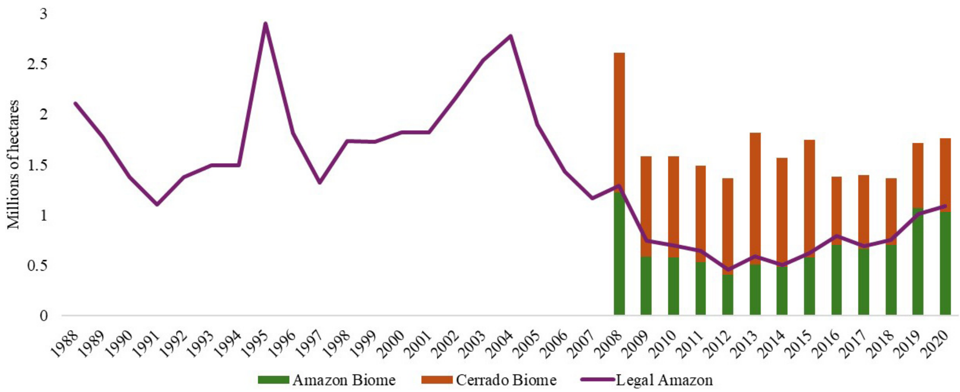

Source: Prepared with data from the TerraBrasilis Platform of the Space Research Institute (INPE).

Graph 4. Increase in deforestation in the Legal Amazon, Amazon biome and Cerrado — 1988 to 2020 (Millions of Hectares).

research aim to assess the impacts of zero deforestation in the Amazon and Cerrado biomes and the economic costs of this policy. Based on the economic costs, we estimate the investments needed in land-intensive sectors to offset these costs, with the goal of offsetting the decline in GDP in all regions of the biomes. We adopt an iterative testing process until this necessary level of investment is found. This will allow us to analyze the impacts of a "Green Growth" scenario, based on the implementation of a zero-deforestation policy combined with sectoral investments, and compare the costs and impacts in each biome.

3.2.1. *Macroeconomic results*

It is expected that the land restriction policy will generate economic losses, mainly in the Amazon and Cerrado biomes, the dimension of this impact will guide the size of sectorial investments. Table 4 shows the results of the main macroeconomic indicators in the zero-deforestation policy in the Amazon and Cerrado biomes. These results are reported as the cumulative percentage deviation (2021–2040) from the baseline scenario. In national terms, the policy would cause a drop of −1.7% in GDP in the period, compared to the Reference Scenario. If compared to zero deforestation in the Amazon biome alone, the drop in national GDP would be −0.5%.

As expected, the impact of the control policy would be higher in the Amazon and Cerrado biome regions. In these regions, the greatest declines in GDP would occur, with emphasis on BA_Cerrado (−6.9%), MT_Cerrado (−4.6%) and MT_Amazônia (−4.3%). The BA_Cerrado region would have a reduction of −6.9% in relation to the baseline scenario, which means that instead of obtaining an accumulated growth of 82% between 2021 and 2040, the region would have a growth of 75.1% when implementing the zero deforestation in the Amazon and Cerrado. This region is an important producer of Cotton and Fibers, with 24% of all

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Table 4. Results of the regional aggregates of the zero-deforestation policy in the Amazon and Cerrado — (accumulated deviation % in relation to the reference scenario).

Bioma	Region	Regional PIB	Household Consumption	Government Spending	Investment	Employment	Export	Import
Amazônia	AC_Amazônia	−3.65	−3.14	−3.14	−6.12	−3.37	1.27	−4.25
	AP_Amazônia	−2.20	−2.12	−2.12	−4.40	−2.35	0.87	−2.82
	AM_Amazônia	−1.96	−1.95	−1.95	−3.97	−2.18	0.36	−2.55
	MA_Amazônia	−2.28	−2.13	−2.13	−4.28	−2.36	0.17	−2.95
	MT_Amazônia	−4.26	−3.37	−3.37	−4.92	−3.59	0.33	−4.13
	PA_Amazônia	−2.76	−2.53	−2.53	−4.53	−2.76	−0.24	−3.06
	RO_Amazônia	−3.38	−2.86	−2.86	−5.43	−3.09	0.35	−3.75
	RR_Amazônia	−2.66	−2.37	−2.37	−5.07	−2.60	0.40	−3.45
	TO_Amazônia	−3.44	−1.85	−1.85	−4.06	−2.08	0.31	−2.96
Caatinga	AL_Caatinga	−1.27	−1.30	−1.30	−3.17	−1.53	0.33	−1.90
	BA_Caatinga	−0.38	−0.50	−0.50	−1.73	−0.74	0.82	−1.05
	CE_Caatinga	−2.56	−2.46	−2.46	−4.52	−2.69	−0.22	−3.24
	MA_Caatinga	−0.65	−0.91	−0.91	−2.43	−1.14	0.34	−1.28
	MG_Caatinga	−0.04	−0.56	−0.56	−0.88	−0.80	0.37	−0.69
	PB_Caatinga	−1.17	−1.22	−1.22	−2.93	−1.45	0.36	−1.75
	PE_Caatinga	−0.68	−0.75	−0.75	−2.21	−0.98	−0.31	−1.33
	PI_Caatinga	−0.56	−0.74	−0.74	−1.71	−0.97	0.35	−1.11
	RN_Caatinga	−1.30	−1.44	−1.44	−3.12	−1.67	0.86	−2.00
	SE_Caatinga	−0.85	−0.91	−0.91	−2.92	−1.14	0.86	−1.53
Cerrado	BA_Cerrado	−6.93	−4.72	−4.72	−10.51	−4.94	0.89	−7.29
	DF_Cerrado	−2.23	−2.25	−2.25	−4.48	−2.48	0.84	−3.27
	GO_Cerrado	−2.52	−2.37	−2.37	−4.46	−2.60	0.39	−3.07
	MA_Cerrado	−2.73	−2.35	−2.35	−4.54	−2.58	0.87	−3.02
	MT_Cerrado	−4.62	−3.61	−3.61	−8.02	−3.84	0.19	−5.37
	MS_Cerrado	−1.80	−1.58	−1.58	−2.88	−1.81	0.56	−2.11
	MG_Cerrado	−2.94	−2.56	−2.56	−5.16	−2.79	1.52	−3.34

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Table 4. (*Continued*)

Bioma	Region	Regional PIB	Household Consumption	Government Spending	Investment	Employment	Export	Import
	PR_Cerrado	−3.07	−2.05	−2.05	−5.03	−2.28	0.36	−2.90
	PI_Cerrado	−2.23	−2.22	−2.22	−4.15	−2.45	0.34	−2.98
	SP_Cerrado	−2.14	−2.10	−2.10	−4.34	−2.33	0.90	−2.78
	TO_Cerrado	−3.31	−2.79	−2.79	−5.57	−3.02	0.26	−4.04
Mata Atlântica	AL_Mata Atlant.	−1.89	−1.91	−1.91	−3.79	−2.14	1.56	−2.57
	BA_Mata Atlant.	−1.71	−1.79	−1.79	−3.52	−2.02	0.11	−2.32
	ES_Mata Atlant.	−1.10	−1.18	−1.18	−2.43	−1.41	0.32	−1.65
	GO_Mata Atlant.	−0.63	−1.16	−1.16	−1.25	−1.39	0.39	−1.29
	MS_Mata Atlant.	0.02	−0.54	−0.54	0.29	−0.78	0.51	−0.35
	MG_Mata Atlant.	−1.51	−1.63	−1.63	−3.30	−1.86	0.64	−2.22
	PB_Mata Atlant.	−2.03	−1.97	−1.97	−3.97	−2.20	0.81	−2.74
	PR_Mata Atlant.	−0.98	−1.10	−1.10	−2.24	−1.33	0.10	−1.63
	PE_Mata Atlant.	−2.00	−1.96	−1.96	−3.91	−2.19	1.21	−2.66
	RJ_Mata Atlant.	−1.67	−1.77	−1.77	−3.74	−2.00	0.99	−2.33
	RN_Mata Atlant.	−1.86	−1.89	−1.89	−3.68	−2.12	−0.26	−2.52
	RS_Mata Atlant.	−0.50	−0.64	−0.64	−1.43	−0.88	0.83	−1.16
	SC_Mata Atlant.	−1.14	−1.22	−1.22	−2.70	−1.45	−0.21	−1.84
	SP_Mata Atlant.	−1.53	−1.60	−1.60	−3.44	−1.83	0.46	−2.25
	SE_Mata Atlant.	−1.80	−1.89	−1.89	−3.72	−2.12	−2.13	−2.41
Pampa	RS_Pampa	−0.76	−0.92	−0.92	−1.89	−1.15	0.25	−1.31
Pantanal	MT_Pantanal	0.76	−0.60	−0.60	1.01	−0.83	1.69	0.17
	MS_Pantanal	0.70	−0.30	−0.30	0.18	−0.53	1.07	−0.34

Source: Own elaboration based on simulation results with the BLUME model.

national production, in addition to being highly dependent on agriculture and livestock. About 48% of all production in the region comes from the agricultural and livestock sectors, especially soy production, which represents 27% of the region's production.

MT_Cerrado and MT_Amazônia, in addition to being important producers in the Soybean and Cattle sectors, are among the three regions with the largest deforested area in the Reference Scenario projection, indicating a strong dependence of the regions on the land production factor. Therefore, in a scenario with restrictions on deforestation, these regions would tend to suffer greater impacts due to the impossibility of expanding activities.

Practically all regions would be negatively impacted by the policy, with the exception of three regions, MS_Mata Atlântica, MT_Pantanal, and MS_Pantanal. Due to the model's productive reallocation mechanism, these regions would have a positive impact on GDP, driven mainly by increased exports and investments. It is also noteworthy that the drop in investment would be the main driver of the drop in GDP in all regions of the model.

In both biomes, GDP growth follows the same trend, however, a lower annual GDP is noted in the land restriction scenario, which implies a decrease in activities and economic downturn. This economic loss can be measured in terms of GDP expenditure. The data indicate that the zero-deforestation policy in the Amazon and Cerrado would cause a greater economic downturn in the Cerrado biome, in the order of BRL 35 billion reais in the accumulated between 2021 and 2040. This value would be equivalent to 0.15% of the projected GDP for this biome. The Amazon, on the other hand, would have a loss of BRL 12 billion in the accumulated period, which would also be equivalent to 0.15% of the projected GDP for the biome.

The estimated economic costs of zero deforestation can be compensated, from the point of view of the methodology adopted, with investment in agricultural activities that increase the productivity of these sectors, compensating for the impossibility of expanding the use of the land factor. From the point of view of operating the model and the simulations, an interactive process was adopted, selecting sectors of land use in the model and adopting investment shocks starting from low values with successive increases, until a null deviation of GDP from all regions against the baseline scenario. Using this procedure, a value close to 1.3% was found for the investment shock.

An investment increase of around 1.3% annually, until 2040, would be enough not only to eliminate the economic loss, but also to generate economic growth with lesser consequences for the environment. The amount invested would be BRL 127 billion in 20 years in the Amazon (BRL 6.4 billion per year) and BRL 415 billion in 20 years in the Cerrado (BRL 20.8 billion per year), in sectors associated with land use. This amount is equivalent to 1.6% of the region's GDP per year during this period.

Therefore, the next step is to analyze the impact of the "Green Growth" scenario in the Amazon and Cerrado, where the zero-deforestation policy will be simulated, combined with 1.3% investment in the agricultural sectors. In national terms, the

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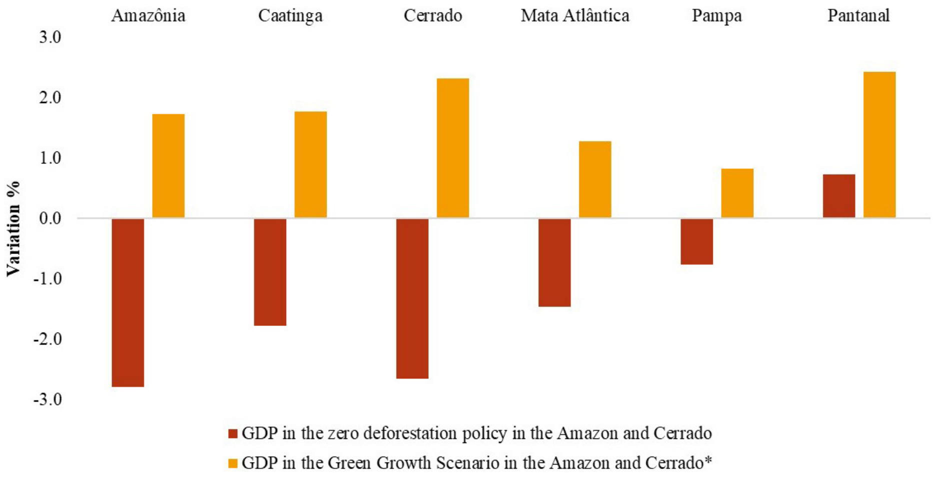

Source: Own elaboration based on simulation results with the BLUME model.
*Green Growth = zero deforestation plus sectoral investments.

Graph 5. GDP variation in the simulation of the zero deforestation policy and the "green growth" Scenario in the Amazon and Cerrado — Brazilian biomes — (accumulated deviation % in relation to the reference scenario).

policy would generate a GDP increase of 1.5% in the period, if compared to the Reference Scenario. The same policy for the Amazon biome alone would generate a national GDP growth of 0.4%. In relation to the biomes, a positive variation of GDP is also noted. Graph 5 shows the GDP variation in the "Green Growth" scenario in the Amazon and Cerrado and only with the zero-deforestation policy, without investments, in both biomes. It is noted that in the scenario with only the land restriction policy, there is a negative impact on the GDP of almost all biomes, with the exception of the Pantanal. By investing 1.3% more in the agricultural sectors, in addition to the GDP becoming positive, there would be economic growth in the biomes. With emphasis on the Cerrado that would have a growth of 2.3% more in the GDP, if compared with the Reference Scenario, where no policy is adopted.

Table 5 shows the results of the regional aggregates of the "Green Growth" scenario in the Amazon and Cerrado. Unlike the scenario in which only zero deforestation is practiced, here most GDP variations are positive, that is, in addition to the environmental gain, the policy would also promote economic growth in most regions of the model. The regions PI_Cerrado, MT_Amazônia, and MS_Cerrado would present the highest positive GDP variations, all around 3%. That is, these regions would grow 3% more, in the accumulated, if compared to the scenario without land or investment restriction policy.

The PI_Cerrado region is a relatively small model region, but with plenty of area available for conversion and soy is an important sector in the region, representing

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Table 5. Results of the regional aggregates of the "green growth" scenario in the Amazon and Cerrado — (accumulated deviation % in relation to the reference scenario).

Bioma	Region	Regional GDP	Household Consumption	Government Spending	Investment	Employment	Export	Import
Amazônia	AC_Amazônia	0.99	1.26	1.26	3.96	1.46	−1.55	2.27
	AP_Amazônia	2.15	2.00	2.00	5.17	2.20	−1.36	3.12
	AM_Amazônia	2.12	1.96	1.96	5.06	2.16	−0.69	2.89
	MA_Amazônia	1.61	1.63	1.63	4.02	1.83	−0.30	2.71
	MT_Amazônia	2.97	2.00	2.00	17.68	2.21	−0.63	6.76
	PA_Amazônia	1.64	1.66	1.66	5.23	1.86	−0.43	2.66
	RO_Amazônia	0.63	0.89	0.89	4.23	1.09	−1.22	2.16
	RR_Amazônia	1.68	1.71	1.71	4.78	1.91	−0.64	2.94
	TO_Amazônia	0.10	1.35	1.35	10.87	1.55	−0.71	2.47
Caatinga	AL_Caatinga	1.65	1.69	1.69	3.38	1.90	−0.78	2.56
	BA_Caatinga	1.36	1.49	1.49	2.07	1.69	−1.13	2.05
	CE_Caatinga	1.84	1.75	1.75	3.56	1.95	−1.35	2.79
	MA_Caatinga	2.51	2.30	2.30	3.93	2.51	−0.76	3.34
	MG_Caatinga	0.90	1.39	1.39	0.38	1.60	−0.80	1.34
	PB_Caatinga	2.04	1.92	1.92	3.84	2.12	−0.80	2.88
	PE_Caatinga	1.72	1.71	1.71	3.26	1.92	−0.39	2.59
	PI_Caatinga	1.71	1.77	1.77	2.57	1.97	−0.78	2.58
	RN_Caatinga	1.84	1.89	1.89	3.48	2.10	−1.20	2.62
	SE_Caatinga	1.57	1.72	1.72	2.96	1.93	−1.19	2.39
Cerrado	BA_Cerrado	1.84	1.34	1.34	18.90	1.54	−1.18	4.33
	DF_Cerrado	1.94	1.93	1.93	3.89	2.14	−1.23	3.24
	GO_Cerrado	2.66	2.43	2.43	8.25	2.63	−0.65	4.27
	MA_Cerrado	2.51	2.15	2.15	8.95	2.35	−1.19	3.75
	MT_Cerrado	2.43	2.23	2.23	13.00	2.44	−0.78	4.72
	MS_Cerrado	2.96	2.45	2.45	9.90	2.66	−0.84	4.68
	MG_Cerrado	2.10	1.92	1.92	7.67	2.13	−2.26	3.47

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Table 5. (*Continued*)

Bioma	Region	Regional GDP	Household Consumption	Government Spending	Investment	Employment	Export	Import
	PR_Cerrado	1.48	0.96	0.96	11.02	1.16	−0.82	2.69
	PI_Cerrado	3.01	2.63	2.63	7.67	2.84	−0.62	4.58
	SP_Cerrado	2.26	2.11	2.11	5.72	2.32	−1.11	3.31
	TO_Cerrado	2.27	2.14	2.14	8.45	2.35	−0.67	4.18
Mata Atlântica	AL_Mata Atlant.	1.73	1.72	1.72	3.47	1.93	−2.23	2.65
	BA_Mata Atlant.	1.61	1.63	1.63	3.25	1.84	−0.29	2.43
	ES_Mata Atlant.	0.88	0.95	0.95	1.94	1.16	−0.48	1.65
	GO_Mata Atlant.	−0.08	0.76	0.76	−1.15	0.96	−0.82	0.57
	MS_Mata Atlant.	−0.55	0.30	0.30	−1.70	0.50	−1.02	−0.15
	MG_Mata Atlant.	1.43	1.50	1.50	2.93	1.71	−0.99	2.33
	PB_Mata Atlant.	1.94	1.85	1.85	3.84	2.05	−1.17	2.95
	PR_Mata Atlant.	0.80	0.91	0.91	1.78	1.11	−0.50	1.66
	PE_Mata Atlant.	1.86	1.75	1.75	3.69	1.95	−1.96	2.79
	RJ_Mata Atlant.	1.42	1.46	1.46	3.16	1.67	−1.42	2.31
	RN_Mata Atlant.	1.75	1.70	1.70	3.54	1.91	−0.84	2.70
	RS_Mata Atlant.	0.73	0.82	0.82	1.48	1.03	−1.16	1.52
	SC_Mata Atlant.	1.13	1.14	1.14	2.42	1.34	−1.01	2.00
	SP_Mata Atlant.	1.28	1.30	1.30	2.86	1.51	−0.71	2.20
	SE_Mata Atlant.	1.70	1.72	1.72	3.48	1.92	2.71	2.55
Pampa	RS_Pampa	0.82	0.91	0.91	1.94	1.11	−0.84	1.54
Pantanal	MT_Pantanal	2.81	2.21	2.21	3.69	2.41	−2.30	3.21
	MS_Pantanal	2.11	1.54	1.54	2.51	1.75	−1.46	2.26

Source: Own elaboration based on simulation results with the BLUME model.

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4.2% of all that is produced. In this case, the growth of PI_Cerrado is justified by the growth of Soy and the increase in aggregate employment and, consequently, in household consumption. MT_Amazônia and MS_Cerrado are regions heavily dependent on agriculture and livestock, being major national producers of Cattle and Soy. Particularly, MT_Amazônia is the third region with the largest area available for conversion and has the second largest deforested area in the accumulated period, in the Reference Scenario. Therefore, the positive impact of the policy indicates that, thanks to the increase in investments, there would be an increase in land productivity capable of increasing sectoral production without expanding production over new areas of land.

3.2.2. *Sectorial results*

First, the results of the zero-deforestation policy in the Amazon and Cerrado biome without investments will be analyzed, and then report the results of the "Green Growth" scenario in the Amazon and Cerrado, where investments of 1, 3% in the agricultural sectors. Finally, a comparison will be made between the two scenarios in the Amazon and Cerrado biomes. Given the nature and scope of the research, the results of the agricultural sectors will be emphasized. Table 6 below shows the results of variations in the level of activity of the agricultural sectors, by region, only in the zero-deforestation policy in the Amazon and Cerrado.

It is observed that the policy, by restricting the possibilities of converting forests to productive use in agriculture, causes a negative impact on agricultural activity in the regions of the Amazon and Cerrado biome. This impact would be more intense in the agricultural sectors of the Amazon biome regions and more intense in the Livestock sectors in the Cerrado biome regions. The Soybean and Cattle sectors, important drivers of deforestation, would reach reductions of -14% in the AC_Amazônia region, in the case of Soybean and -23% in BA_Cerrado, in the case of Cattle. Both sectors are representative in the biomes. The Amazon, for example, is responsible for 14% of the national production of Soy and 24% of the national production of Cattle. The Cerrado, on the other hand, holds 49% of all soybean production and 38% of beef production. Therefore, a land restriction policy would cause a greater negative impact in regions intensive in agriculture and livestock, mainly in the Soybean and Cattle sectors.

The positive impact observed in the regions of the other biomes is due to the fact that these regions would not face the increase in production costs due to land restriction, caused by the Zero Deforestation policy. Thus, there would be a relative displacement of productive activities towards these regions. It is interesting to observe that the regions of the Caatinga biome would present the greatest increases in the production of the sectors, however, many of these sectors are not representative in the region. The most important sector in the Caatinga biome is Citrus Fruits, whose biome is responsible for 43% of national production. It is worth remembering that the model's transition process cannot capture the quality of land available for conversion, it is

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Table 6. Variation of sectoral activity by region in the zero-deforestation policy in the Amazon and Cerrado — (accumulated deviation % in relation to the Reference Scenario).

Biome	Region	Rice	Wheat and other cereals	Corn grain	Cotton and other fibers	Sugar cane	Soybean grain	Cassava	Tobacco leaf	Citrus fruits	Beans grain	Others Temporary	Orange	Coffee grain	Others Permanent	Cattle	Other animals	Cow's milk	Milk from other animals	Swine	Forestry	Plant extraction
Amazônia	AC_AM	-7.6	-14.3	-10.1	6.6	-0.8	-14.3	-13.1	-0.6	-3.9	-19.1	-6.6	-6.0	-17.0	-1.2	-15.6	-11.2	-21.5	-5.5	-19.9	-14.3	-7.3
	AP_AM	-2.4	-5.1	-0.4	0.8	-1.0	-2.6	-2.8	-1.9	-2.0	-3.9	-0.6	1.4	-3.3	-1.4	-4.5	-4.6	-6.1	-1.1	-7.1	-7.7	-3.9
	AM_AM	-2.9	-5.1	1.1	0.8	-2.6	-2.6	-3.1	-2.0	-1.9	-5.7	-1.4	-0.7	-4.2	1.2	-1.5	-4.4	-7.8	-1.3	-6.4	-5.9	-3.7
	MA_AM	-7.1	-11.6	-9.3	-7.0	-6.6	-10.8	-9.3	-4.9	-3.0	-13.7	-7.3	-9.8	-10.5	-7.4	-10.4	-8.8	-13.4	-4.7	-12.6	-7.0	-2.4
	MT_AM	-4.9	-5.2	-3.2	0.5	-3.7	-3.0	-3.3	-2.0	-1.7	-1.7	-5.6	0.5	-5.5	1.5	-15.9	-12.5	-21.0	-7.7	-21.5	-4.7	0.3
	PA_AM	-5.8	-8.0	-5.9	-2.6	-0.5	-6.8	-5.9	-2.9	-2.5	-10.4	-1.3	-1.3	-7.6	-5.9	-13.2	-9.5	-17.6	-5.8	-16.4	-8.0	-2.5
	RO_AM	-6.1	-6.3	-5.0	-0.7	-3.1	-4.4	-4.3	-2.4	-2.4	-8.1	-1.5	-1.4	-7.2	-0.8	-11.4	-10.3	-17.8	-5.2	-14.2	-14.3	-4.8
	RR_AM	-11.7	-11.9	-9.8	-7.1	-2.8	-11.7	-9.2	-5.8	-2.8	-11.3	-8.1	-3.5	-11.2	0.1	-11.6	-7.8	-14.9	-2.0	-13.6	-12.1	-6.7
	TO_AM	-3.1	-5.8	-3.7	-0.4	-1.4	-3.7	-2.7	-2.3	-1.9	-6.5	-0.2	-3.6	-4.1	-1.4	-5.7	-5.9	-8.5	-1.5	-6.3	-16.3	-4.5
Caatinga	AL_CA	-3.7	-4.1	-1.5	6.0	-2.9	-2.2	-2.5	-2.4	-2.3	-3.4	-4.5	-2.7	-2.8	1.5	8.4	0.0	3.3	2.0	3.3	-2.4	-0.6
	BA_CA	-0.2	-0.9	3.0	7.4	0.5	2.1	0.8	-0.4	-0.9	1.4	0.3	1.6	0.9	0.4	11.2	1.2	5.8	2.8	5.6	-0.6	0.9
	CE_CA	-12.3	-15.9	-10.5	6.3	-11.7	-15.3	-12.7	-7.8	-5.5	-18.3	-15.4	-11.7	-15.2	-10.6	-4.2	-6.8	-9.4	-2.8	-9.7	-5.9	-4.4
	MA_CA	0.4	-0.2	4.5	6.1	1.4	4.1	2.0	-0.4	-0.8	4.0	0.1	2.4	2.3	1.6	19.0	2.1	11.7	4.0	10.1	-0.7	1.3
	MG_CA	0.2	-0.6	3.1	7.8	0.9	3.1	1.5	-0.5	-0.7	2.3	-0.2	2.0	1.6	1.7	9.0	0.8	4.7	2.7	5.0	-0.8	1.3
	PB_CA	-0.3	-1.1	2.6	6.5	0.1	1.6	0.5	-0.7	-1.2	0.9	0.0	1.6	0.6	1.5	12.8	1.4	6.9	3.2	6.8	-0.6	1.0
	PE_CA	-0.2	-1.1	2.9	6.3	0.2	1.7	0.5	-0.7	-0.9	0.9	-0.4	1.1	0.5	0.7	12.3	1.4	6.5	3.0	6.3	-0.5	1.0
	PI_CA	0.4	-0.1	3.8	7.6	1.8	3.3	1.8	-0.3	-0.8	2.8	0.2	1.8	1.9	1.6	13.4	1.8	7.4	3.4	7.1	-0.4	1.3
	RN_CA	0.0	-0.9	3.1	7.4	0.2	2.1	1.0	-0.6	-1.1	1.6	-0.6	1.0	1.0	0.8	14.7	1.7	8.6	3.3	8.1	-0.4	1.1
	SE_CA	-2.4	-2.7	0.7	1.9	-1.1	-0.1	-0.9	-1.4	-1.6	-1.3	-2.8	-0.1	-1.1	-3.2	7.6	-0.4	2.4	1.7	3.0	-2.6	-0.1
Cerrado	BA_CE	-6.3	-10.8	-10.5	-5.7	-0.9	-10.2	-8.8	-1.0	-2.8	-8.5	-18.8	-9.2	-8.2	-14.0	-22.7	-15.2	-26.8	-8.2	-25.9	-6.8	-2.4
	DF_CE	-6.4	-7.5	-5.3	-1.7	-4.9	-4.8	-1.8	-2.7	-2.0	-3.2	-9.0	-2.6	-4.4	-5.8	-17.7	-13.3	-18.1	-7.5	-21.8	-4.7	-0.3
	GO_CE	-4.1	-4.8	-2.1	1.2	-3.3	-1.7	-1.3	-1.0	-1.4	-0.8	-1.2	-2.0	-1.9	-5.4	-9.7	-8.4	-11.1	-3.7	-13.2	-2.0	1.0
	MA_CE	-2.7	-5.7	-3.4	0.2	-4.9	-3.6	-3.4	-2.1	-1.5	-5.3	-3.5	-2.6	-4.0	-0.4	-10.9	-8.3	-16.9	-3.3	-14.3	-11.0	-4.3
	MT_CE	-8.8	-8.8	-7.9	-4.0	-8.4	-7.5	-6.4	-3.4	-2.1	-6.1	-8.8	-4.4	-10.1	-0.2	-16.1	-11.9	-19.2	-7.8	-20.4	-8.4	-0.5
	MS_CE	-2.9	-3.6	-0.7	2.4	-2.1	-0.4	-0.5	-1.4	-1.3	-0.3	-4.7	-1.0	-1.2	-3.5	-6.1	-5.9	-7.9	-2.2	-9.2	-4.2	0.6
	MG_CE	-4.9	-7.0	-4.5	-0.9	-5.1	-4.1	-3.0	-1.1	-1.7	-3.7	-4.5	-4.4	-4.3	-2.3	-10.0	-8.9	-12.4	-4.1	-15.2	-2.3	0.4
	PR_CE	-6.0	-8.0	-6.4	-3.3	-7.1	-6.0	-5.3	-3.5	-1.9	-5.0	-11.6	-6.5	-6.3	-4.6	-15.3	-14.3	-16.9	-11.1	-19.4	-2.6	0.8
	PI_CE	-3.3	-4.4	-1.9	1.9	-3.3	-1.8	-1.2	-1.5	-1.2	-3.1	-7.9	-1.1	-2.6	0.1	-11.1	-8.2	-17.4	-2.1	-14.4	-12.6	-3.2
	SP_CE	-5.1	-5.8	-3.5	-0.7	-4.4	-3.2	-0.1	-2.3	-1.5	-2.8	-0.1	-3.6	-3.5	-7.3	-7.8	-7.8	-9.4	-5.4	-11.1	-1.7	1.1
	TO_CE	-6.5	-6.8	-5.3	-1.1	-6.0	-5.1	-4.0	-2.4	-1.6	-5.7	-2.8	-3.6	-5.4	-3.7	-12.1	-8.9	-16.8	-2.8	-14.0	-15.4	-6.5
Mata Atlântica	AL_MA	-0.6	-1.7	1.8	3.1	-0.9	1.2	0.0	-0.8	-1.4	0.3	0.2	1.7	0.1	-1.6	8.4	0.3	5.2	2.6	3.0	-1.3	0.9
	BA_MA	-0.4	-0.8	2.8	4.7	0.6	2.6	0.7	-0.3	-1.1	1.9	0.3	2.3	1.2	1.0	7.1	0.3	4.6	2.5	3.6	-0.5	1.2
	ES_MA	-0.3	-0.9	3.3	4.5	0.4	2.4	1.1	-0.6	-1.0	1.5	0.4	2.5	1.0	-0.2	6.8	0.4	3.6	2.3	2.1	-0.7	1.2
	GO_MA	-0.7	-1.1	2.2	4.5	0.2	2.3	0.8	-0.7	-0.8	2.7	-1.9	1.3	1.1	-0.9	6.1	0.0	3.6	2.1	3.6	-0.9	1.2
	MS_MA	-0.4	-0.8	2.5	5.0	0.5	2.7	1.8	-0.6	-1.0	3.0	-0.6	1.6	1.2	-0.5	4.6	-0.2	2.2	1.8	2.0	-0.7	1.3
	MG_MA	-0.4	-1.0	2.4	4.4	0.6	2.2	1.1	0.1	-0.9	1.2	-0.4	1.5	1.0	1.0	7.5	0.6	3.5	2.4	1.9	-0.6	1.3
	PB_MA	-1.0	-1.4	2.4	7.1	-0.5	1.6	0.2	-0.8	-1.2	0.7	0.6	1.6	0.4	-1.2	9.1	0.2	5.1	2.4	4.8	-0.8	1.1
	PR_MA	-0.4	-0.7	2.1	4.4	0.4	2.2	1.4	-0.5	-0.8	1.6	0.0	1.3	1.2	0.2	6.6	0.6	2.8	2.3	1.8	-0.4	1.2
	PE_MA	-1.0	-1.4	2.7	3.5	-0.4	1.6	0.2	-0.7	-1.2	0.7	-0.1	1.8	0.5	1.1	9.0	0.0	4.8	2.5	4.2	-1.2	0.9
	RJ_MA	-0.8	-1.1	2.2	3.9	0.5	1.9	1.0	-0.6	-0.8	1.1	0.5	1.6	0.7	-0.5	7.6	0.2	4.1	2.6	3.7	-0.4	1.6
	RN_MA	-0.2	-0.6	3.1	4.4	0.4	2.6	1.2	-0.5	-1.3	2.1	-0.3	1.4	1.3	0.1	12.7	1.1	7.8	3.3	7.2	-0.6	1.2
	RS_MA	-0.1	-0.5	2.8	4.5	2.0	2.6	1.2	-0.6	-0.9	1.9	-0.1	2.4	1.4	1.1	9.7	1.4	4.6	3.1	4.3	-0.3	1.5
	SC_MA	0.1	-0.4	3.0	4.5	1.9	2.7	1.2	-0.3	-0.8	1.8	0.2	2.0	1.5	0.4	9.9	1.5	4.6	3.1	3.7	-0.4	1.3
	SP_MA	-0.6	-0.9	2.3	4.5	0.3	2.3	1.7	-0.6	-0.5	2.1	0.5	1.2	1.2	-0.5	7.2	0.6	4.3	2.5	2.7	-0.4	1.4
	SE_MA	-0.7	-1.5	1.8	3.8	-0.4	1.7	0.3	-0.6	-1.2	0.7	0.3	1.4	0.5	-1.4	7.2	-0.2	3.4	2.0	2.9	-1.0	0.6
Pampa	RS_PP	0.2	-0.2	3.3	5.1	2.1	2.9	1.7	-0.4	-0.8	2.6	0.2	2.0	1.8	1.4	8.4	1.5	5.8	3.2	5.1	-0.3	1.3
Pantanal	MT_PT	0.5	0.0	4.3	6.2	2.2	4.1	2.4	-0.4	-0.9	3.8	0.8	2.5	2.5	0.8	12.0	1.9	8.1	3.7	7.3	-0.1	1.3
	MS_PT	0.3	-0.1	3.9	5.8	2.5	3.7	2.2	-0.4	-0.6	3.3	0.7	2.3	2.2	0.8	10.4	1.9	7.5	3.6	7.8	-0.5	1.3

Note: *The negative values in this table occur in regions where the sectoral production of the respective good is very small.
Source: Own elaboration based on simulation results with the BLUME model.

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Table 7. Variation in sectoral activity by region in the "Green Growth" Scenario in the Amazon and Cerrado — (accumulated deviation % in relation to the reference scenario).

Biome	Region	Rice	Wheat and other cereals	Corn grain	Cotton and other fibers	Sugar cane	Soybean grain	Cassava	Tobacco leaf	Citrus fruits	Beans grain	Others Temporary	Orange	Coffee grain	Others Permanent	Cattle	Other animals	Cow's milk	Milk from other animals	Swine	Forestry	Plant extraction
Amazônia	AC_AM	2.4	2.1	-1.3	3.4	3.8	0.9	-1.4	11.2	9.9	-10.6	3.0	-0.4	-5.2	8.7	-12.0	-3.3	-19.7	0.6	-17.6	6.1	6.9
	AP_AM	7.0	8.3	5.4	8.5	7.8	8.2	6.6	9.1	10.2	4.0	7.6	3.6	7.8	8.7	-1.7	3.3	-2.7	2.3	-5.6	8.2	8.3
	AM_AM	7.6	8.7	4.1	8.9	8.4	8.6	6.7	9.2	10.5	1.9	7.3	6.1	6.8	10.6	2.0	2.6	-4.9	1.4	-3.9	9.6	8.6
	MA_AM	2.6	2.6	-0.3	3.0	3.2	1.8	1.5	6.7	10.6	-7.1	5.5	0.1	2.4	6.2	-7.4	-3.0	-11.3	-1.5	-11.4	9.2	9.2
	MT_AM	8.3	8.5	7.0	8.7	8.4	8.4	8.2	9.2	11.6	9.3	7.4	4.6	3.1	9.9	-13.3	-6.3	-21.0	-3.9	-19.1	11.0	11.5
	PA_AM	6.2	6.6	4.3	6.9	6.3	6.1	4.7	8.5	10.6	-2.3	7.8	3.8	4.8	6.0	-9.6	-2.6	-15.7	-1.9	-14.5	9.3	9.4
	RO_AM	7.7	7.9	6.1	8.1	7.6	7.7	6.2	9.1	10.4	-0.5	8.1	5.2	2.2	9.8	-8.2	-2.5	-16.8	-0.4	-12.9	5.5	9.4
	RR_AM	3.6	3.6	0.5	4.0	4.7	2.7	2.3	4.8	10.7	0.3	1.6	1.2	3.1	8.9	-7.3	-1.3	-11.5	4.4	-11.5	6.8	6.5
	TO_AM	6.3	7.3	5.5	7.5	6.9	7.1	7.7	8.7	10.9	-0.4	8.2	5.7	6.9	9.4	-2.9	0.4	-7.7	4.3	-5.8	2.9	9.3
Caatinga	AL_CA	-4.7	-4.3	-7.1	-10.7	-5.7	-7.7	-4.6	-2.2	-1.8	-5.8	-6.3	-5.7	-5.7	-1.4	9.3	0.5	3.0	0.3	3.2	-4.2	-8.3
	BA_CA	-1.8	-1.3	-5.0	-10.8	-3.6	-6.0	-2.0	-0.2	-0.5	-2.4	-3.1	-3.3	-3.2	-1.7	12.2	1.9	5.6	1.3	5.7	-2.8	-6.7
	CE_CA	-1.5	-0.7	-4.9	-10.8	-3.3	-5.2	-1.3	-0.1	-0.1	-1.5	-2.6	-2.9	-2.6	-1.4	14.9	2.6	6.9	1.7	6.7	-3.0	-6.4
	MA_CA	-1.2	0.0	-5.7	-9.6	-3.1	-6.2	-1.3	0.3	-0.4	-1.0	-2.7	-2.8	-2.6	-1.2	21.2	3.0	11.7	2.0	10.6	-2.7	-6.3
	MG_CA	-1.7	-1.1	-5.9	-11.1	-4.0	-6.8	-2.3	0.0	-0.7	-2.7	-3.5	-3.5	-3.4	-1.3	9.6	1.2	4.3	0.7	4.8	-2.8	-7.1
	PB_CA	-1.8	-1.3	-5.0	-10.2	-3.3	-5.5	-2.0	-0.4	-0.4	-2.2	-3.1	-3.2	-3.0	-1.3	14.2	2.2	6.7	1.5	7.0	-3.0	-7.0
	PE_CA	-1.9	-1.4	-5.0	-10.1	-3.6	-5.7	-2.0	-0.4	-0.7	-2.4	-3.1	-3.3	-3.4	-1.4	13.5	2.0	6.3	1.4	6.4	-3.1	-5.9
	PI_CA	-1.2	-0.4	-4.7	-10.9	-3.5	-5.2	-1.3	0.1	-0.2	-1.2	-2.3	-2.4	-2.4	-1.3	14.6	2.4	7.2	1.7	7.3	-2.4	-6.3
	RN_CA	-1.6	-1.1	-5.2	-10.8	-3.3	-5.7	-1.7	-0.2	-0.2	-2.1	-2.9	-3.1	-3.0	-1.5	16.6	2.6	8.4	1.7	8.5	-2.9	-6.7
	SE_CA	-3.6	-3.0	-6.7	-10.0	-5.1	-7.7	-3.7	-1.0	-0.8	-5.0	-5.3	-4.6	-4.9	-4.4	8.4	0.1	2.0	0.1	2.9	-4.5	-7.9
Cerrado	BA_CE	3.9	4.0	1.3	4.4	4.7	3.2	3.7	10.8	11.5	3.2	-2.7	1.6	6.0	1.0	-21.3	-9.7	-26.7	-2.5	-26.2	9.6	9.8
	DF_CE	6.0	6.3	4.2	6.3	5.9	5.8	9.7	8.3	10.9	6.9	2.7	3.3	7.5	5.9	-16.2	-7.2	-15.9	-1.5	-21.0	10.6	10.8
	GO_CE	8.4	8.7	7.1	8.6	8.4	8.3	9.4	10.5	11.7	8.9	10.9	6.9	9.5	6.6	-7.3	-2.0	-9.5	1.7	-11.6	12.2	11.8
	MA_CE	6.8	8.3	6.7	8.6	8.4	8.3	7.0	9.1	11.7	2.3	7.2	6.6	7.9	10.3	-7.4	-1.3	-13.9	1.7	-12.5	8.0	8.0
	MT_CE	4.8	4.7	2.4	5.0	4.6	4.2	5.4	7.8	11.3	5.2	4.3	2.0	-2.6	8.2	-13.7	-5.2	-19.0	-5.9	-18.8	9.4	11.3
	MS_CE	9.1	9.4	8.1	9.3	9.1	9.2	9.6	9.4	11.4	8.3	6.6	7.9	8.7	8.6	-4.0	0.3	-6.9	2.3	-7.8	11.0	11.6
	MG_CE	6.5	7.0	5.0	7.0	6.6	6.6	8.1	10.5	11.6	6.3	7.8	5.0	7.3	8.2	-8.0	-3.0	-10.5	1.1	-13.5	11.6	11.1
	PR_CE	2.6	2.9	0.4	2.9	2.5	2.1	3.2	6.6	10.7	3.3	-4.2	0.4	2.1	5.2	-18.1	-15.4	-18.5	-10.8	-22.4	10.4	11.4
	PI_CE	8.9	9.3	8.2	9.5	9.4	9.4	9.3	9.4	11.9	5.0	5.4	7.9	8.8	12.2	-7.4	-1.9	-15.1	4.4	-12.9	6.8	9.7
	SP_CE	5.9	6.0	4.0	6.0	5.6	5.6	10.9	8.1	11.2	6.0	11.0	3.9	6.7	1.2	-8.7	-3.9	-10.5	-5.9	-12.6	11.3	11.6
	TO_CE	7.5	7.6	5.8	7.9	7.7	7.4	7.2	8.9	11.6	4.6	8.7	6.0	7.1	10.3	-8.3	-1.2	-14.5	3.8	-12.5	4.5	7.7
Mata Atlântica	AL_MA	-2.0	-1.6	-5.8	-9.0	-3.5	-6.4	-2.2	-0.4	-0.5	-3.0	-3.4	-3.5	-3.6	-2.3	10.4	1.6	5.6	1.1	3.8	-3.2	-5.7
	BA_MA	-1.9	-1.1	-5.8	-9.5	-3.9	-6.5	-1.5	-0.1	-0.1	-2.6	-3.2	-3.3	-3.1	-1.8	8.5	1.5	4.5	1.0	3.7	-2.4	-6.7
	ES_MA	-1.7	-1.1	-6.0	-9.5	-3.7	-6.4	-2.3	0.0	-0.4	-2.7	-3.4	-3.4	-3.4	-1.9	8.1	1.1	4.0	0.8	2.7	-2.6	-5.5
	GO_MA	-2.0	-1.3	-5.9	-9.8	-3.8	-6.7	-2.6	-0.1	-0.8	-2.3	-4.3	-3.6	-3.5	-2.2	7.4	0.7	4.0	0.6	4.3	-2.9	-6.9
	MS_MA	-1.4	-0.6	-5.2	-9.4	-3.2	-6.0	-2.0	0.2	-0.6	-2.1	-3.5	-3.0	-3.1	-1.5	8.0	1.6	5.0	1.3	4.7	-2.8	-5.9
	MG_MA	-1.9	-1.4	-5.3	-9.4	-3.7	-6.3	-2.2	-0.2	-0.4	-2.2	-3.5	-3.5	-3.4	-1.4	8.8	1.4	3.8	0.9	2.5	-2.3	-6.8
	PB_MA	-2.2	-1.5	-5.8	-10.7	-3.4	-6.2	-2.0	-0.4	-0.4	-2.7	-3.2	-3.5	-3.4	-1.9	10.9	1.6	5.2	0.9	5.3	-2.7	-7.1
	PR_MA	-0.7	0.1	-3.7	-8.0	-2.1	-4.3	-1.3	0.3	-0.3	-0.9	-2.5	-2.1	-1.9	-0.6	9.9	2.4	5.4	2.1	4.4	-1.8	-5.6
	PE_MA	-2.2	-1.4	-5.9	-8.9	-3.4	-6.3	-2.2	-0.4	-0.4	-2.7	-3.0	-3.5	-3.4	-1.1	11.1	1.7	5.3	1.1	4.9	-2.8	-6.0
	RJ_MA	-2.2	-1.6	-5.9	-9.3	-4.0	-6.4	-2.5	-0.3	-0.8	-3.1	-3.4	-3.5	-3.7	-2.5	8.7	1.2	4.0	0.8	3.8	-2.7	-7.8
	RN_MA	-1.1	-0.3	-5.0	-8.1	-2.5	-5.1	-1.4	0.1	-0.1	-1.2	-2.4	-2.5	-2.3	-0.7	15.2	2.7	8.6	1.9	8.3	-2.3	-5.5
	RS_MA	-0.6	0.2	-3.8	-7.8	-3.9	-4.6	-1.1	0.4	-0.2	-1.1	-2.3	-2.6	-1.9	-0.7	12.3	2.7	6.6	2.1	6.2	-2.4	-6.7
	SC_MA	-1.0	-0.2	-4.5	-7.9	-3.7	-4.8	-1.4	0.1	-0.3	-1.2	-3.0	-2.6	-2.2	-0.8	11.3	2.2	5.4	1.8	4.6	-1.7	-5.8
	SP_MA	-1.3	-0.8	-5.0	-8.9	-2.7	-5.6	-1.9	0.2	-0.9	-1.8	-3.1	-2.7	-2.7	-1.4	9.6	1.9	5.4	1.4	4.2	-2.6	-5.9
	SE_MA	-2.2	-1.7	-6.2	-9.7	-4.1	-7.0	-2.3	-0.3	-0.5	-3.5	-3.5	-3.7	-3.9	-2.3	8.7	0.8	3.5	0.5	3.3	-3.2	-7.0
Pampa	RS_PP	-0.5	0.3	-4.0	-8.1	-3.9	-4.3	-1.2	0.4	-0.2	-1.0	-2.4	-2.1	-1.8	-0.7	10.8	2.8	7.4	2.3	7.0	-2.0	-5.8
Pantanal	MT_PT	-1.2	-0.2	-4.9	-9.5	-3.9	-6.0	-1.5	0.3	-0.4	-1.5	-3.3	-2.8	-2.6	-0.7	12.7	2.3	7.8	1.7	7.3	-2.4	-5.4
	MS_PT	-1.0	-0.2	-4.7	-9.1	-4.3	-5.7	-1.4	0.3	-0.6	-1.5	-3.2	-2.7	-2.5	-0.8	11.1	2.3	7.4	1.7	8.0	-2.5	-5.3

Note: *The negative values in this table occur in regions where the sectoral production of the respective good is very small.
Source: Own elaboration based on simulation results with the BLUME model.

based on the amount of land available, the productive structure and intersectoral and interregional relationships.

When we consider the "Green Growth" scenario in the Amazon and Cerrado, a reversal in the impact of production in the agricultural sectors is observed in both the Amazon and Cerrado biomes. The agricultural sectors would show increases in production while the livestock sectors would show reductions in their activities. The results of variations in the level of sectoral activity, by region, in the "Green Growth" scenario in the Amazon and Cerrado are shown in Table 7.

The decline in the livestock sectors indicates that the increase in land productivity in these sectors would not be enough to generate growth in activities. Investments greater than 1.3% would be required to offset the land use restriction. This is because the livestock sectors are more dependent on the use of the land factor. As seen in the results of the Reference Scenario, the opening of new areas in the Amazon is mainly due to the growth of livestock. Therefore, restricting this factor would have a more significant impact on these sectors. In addition, the productivity of land destined for agricultural products would be greater than the productivity of land for livestock, which encourages the migration of activities in a scenario with financial incentives to do so.

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3.2.3. *Results of land use change and emissions*

In the Reference Scenario, where there are no restrictions on the use of Natural Forest, accumulated deforestation would reach 57 Mha in 2040. In the "Green Growth" scenario in the Amazon and Cerrado, the deforestation projection would be 21 Mha of forest loss. In other words, there would be a 63% reduction in deforestation. For comparison, if the policy were applied only in the Amazon biome, the reduction would be 31%. The reduction of the area of Natural Forest implies the increase of areas of Crop, Pasture, and Planted Forest. Due to the land transition mechanism of the BLUME model, it is to be expected that the Pasture areas are more impacted since it is assumed that the Natural Forest areas are first converted into pasture and later into Crops. In the "Green Growth" scenario in the Amazon and Cerrado, around 9.5 Mha of Pasture would be opened in the accumulated until 2040, 27 Mha less than in the Reference Scenario, and 12 Mha less if compared to the land contention policy only in the Amazon biome. The Lavoura areas would increase by 9.5 Mha, 8 Mha less than in the scenario without land restrictions.

The "Green Growth" scenario in the Amazon and Cerrado would cause an increase in deforestation in all regions of the other biomes, with emphasis on the BA_Caatinga region, which would present the largest amount of lost area of Natural Forest, clearly to the detriment of Pasture. This region is the largest producer in the other animals' sector, with 12% of national production, in addition to being a region whose productive structure is dependent on agriculture and livestock. In addition, BA_Caatinga has one of the lowest variations in land prices in the livestock sectors, encouraging an increase

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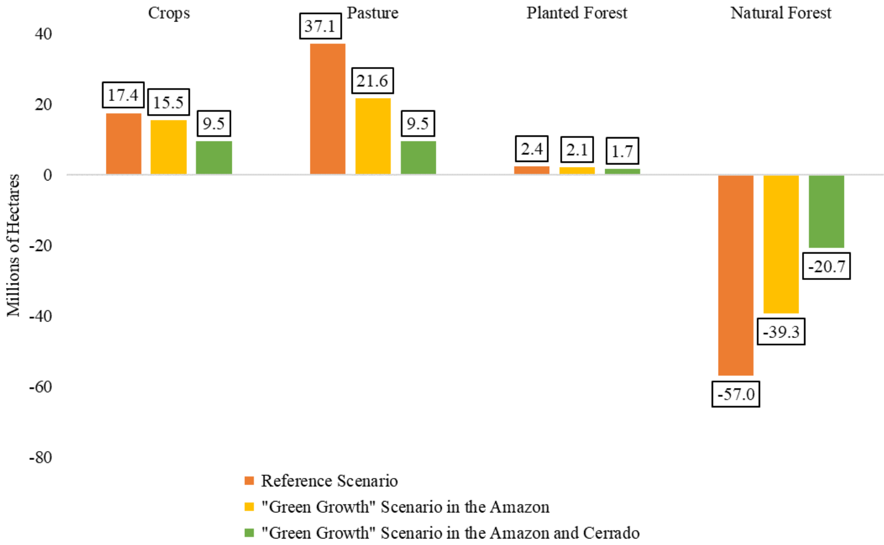


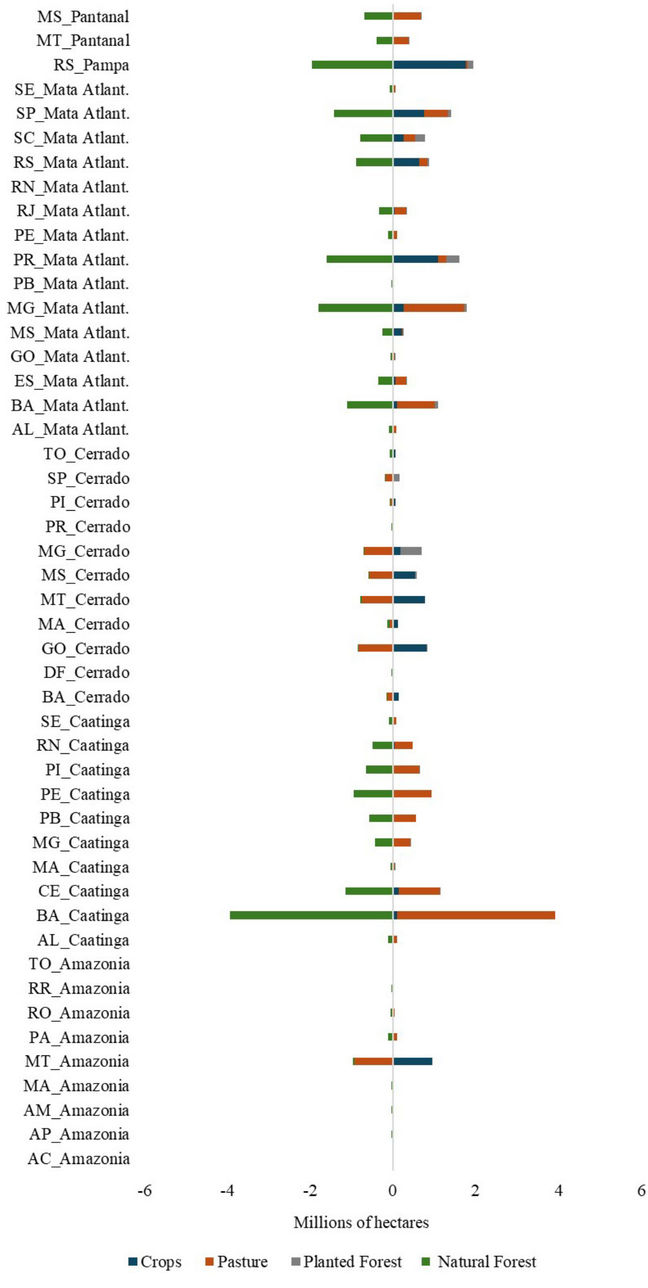
Source: Own elaboration based on simulation results with the BLUME model.

Graph 6. Variation of different land uses in the Reference Scenario, "Green Growth" Scenario in the Amazon and Cerrado and "Green Growth" Scenario only in the Amazon — accumulated from 2021 to 2040 (Million Hectares).

in the productive use of these areas. The region is also the third with the largest amount of area available for conversion, which also explains the impact of the policy. In Graph 6, below, one can find the results of the variation of different types of land uses (in Mha) by region.

In general, the fall in Pasture in most regions, especially in the Cerrado, would be to the detriment of the increase in Cropland. The region that would show the greatest reduction in Pasture areas would be MT_Amazônia. Due to the restriction on the use of new land in the biomes, and investments in the agricultural sectors, these regions would reallocate land from livestock for agricultural use, especially for the production of Soy, the most significant sector in the Cerrado. The MG_Cerrado region would present the greatest expansion of land destined to planted forest. This region is an important national producer in the Silviculture sector, with 9.6% of national production.

The variation in land use in biomes can be seen in Graph 7 below. The variation in the Pasture area in the Cerrado would clearly be to the detriment of the expansion of the Crop areas. The Atlantic Forest biome, on the other hand, would present the highest variation of Natural Forest in the accumulated, totaling 9 Mha deforested, followed by the Caatinga, with 8.4 Mha. The deforestation of the Atlantic Forest would occur both for the expansion of Pasture and Lavoura, since the biome is an important producer of most agricultural and livestock sectors. For example, 80% of Wheat production occurs in the biome, 67% of Pork production, among others.



Source: Own elaboration based on simulation results with the BLUME model.

Graph 7. Variation in land use according to use category and region in the "Green Growth" Scenario in the Amazon and Cerrado — accumulated from 2021 to 2040 (Millions of Hectares).

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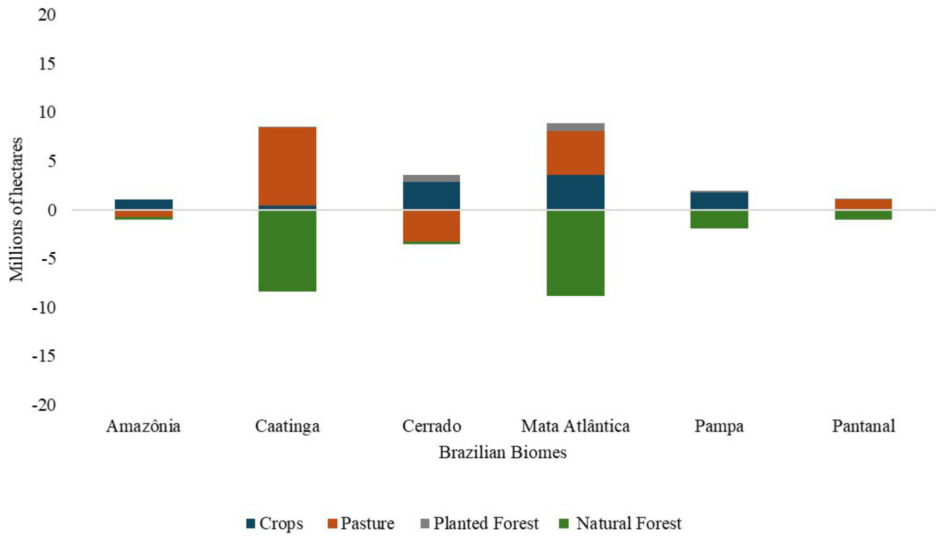

Source: Own elaboration based on simulation results with the BLUME model.

Graph 8. Variation in land use by biomes in the "Green Growth" Scenario in the Amazon and Cerrado — accumulated from 2021 to 2040 (Millions of Hectares).

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Regarding emissions, the "Green Growth" scenario in the Amazon and Cerrado would cause a considerable drop in emissions from the LULUCF sector, compared to the Reference Scenario. As shown in Graph 8 below, from 2021 to 2040, the sector would emit 4,024,585 Gg of CO_2eq, representing a 20% reduction in emissions compared to the Reference Scenario. The transitions of the Natural Forest would present the biggest drops in emissions, totaling 935,617 Gg of CO_2eq less in the atmosphere, in the accumulated, in relation to the Reference Scenario. This means that the policy would prevent 935,617 Gg of CO_2eq from being emitted in the accumulated period. This would be equivalent to more than triple the net total issued by the sector in 2015. However, if compared with a "Green Growth" scenario only in the Amazon biome, the drop in emissions would have a difference of 5% between the scenarios.

Regarding total emissions, considering the other emitting sectors, the projections would indicate an accumulated emission of 31,485,251 Gg of CO_2eq, which would be equivalent to an annual average of 1,574,262 Gg of CO_2eq. The total annual emissions by sector are shown in Graph 9. A decrease of -20% in emissions is observed compared to the Reference Scenario and -1% in relation to the "Green Growth" scenario in the Amazon. This drop would be mainly driven by the decrease in emissions from the LULUCF sector, since the other sectors would show a slight increase in emissions. The fuel sector, for example, would emit 0.37% more in the accumulated period, if compared to the Reference Scenario. In addition, projections would indicate a total of 1,407,290 Gg of CO_2eq emitted in 2025 and 1,560,635 Gg of CO_2eq in 2030. Thus, the "Green Growth" Scenario in the Amazon and Cerrado did not make Brazil

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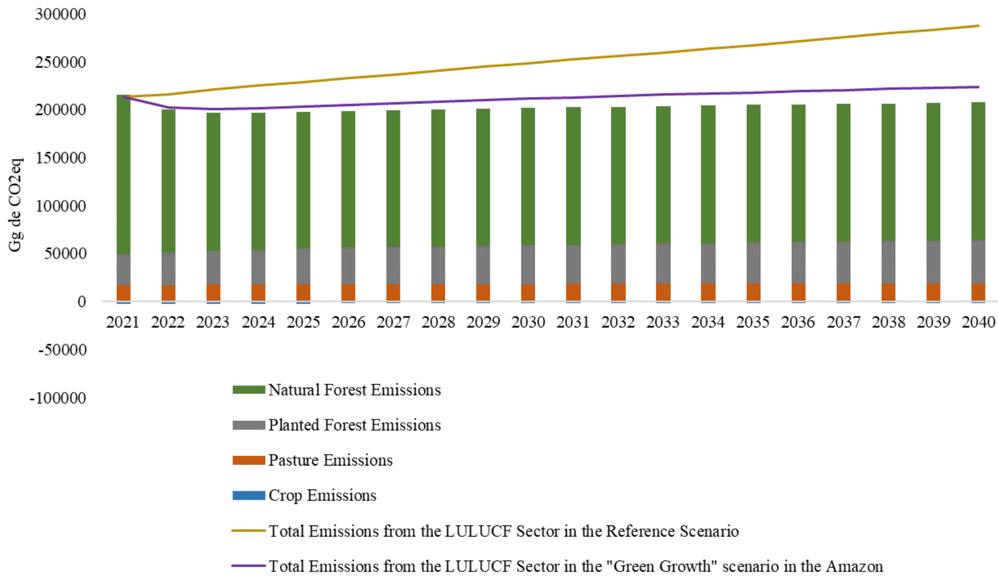
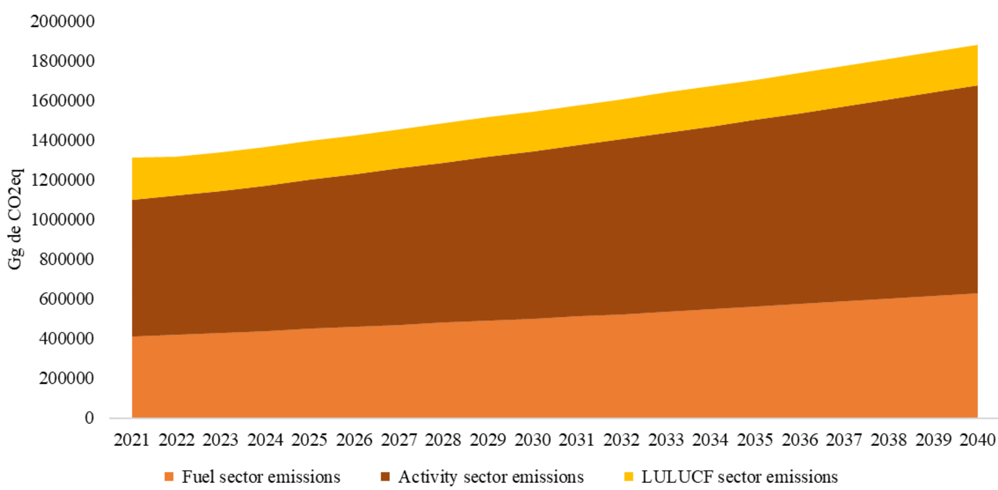


Source: Own elaboration based on simulation results with the BLUME model.
*Green Growth = zero deforestation plus sectoral investments.

Graph 9. Variation of emissions from land use changes by use category in the "Green Growth" Scenario in the Amazon and Cerrado. Lines with the total emissions from Reference Scenario and "Green Growth" Scenario only in the Amazon — annual from 2021 to 2040 (Gg of CO_2eq).



Source: Own elaboration based on simulation results with the BLUME model.
*Green Growth = zero deforestation plus sectoral investments.

Graph 10. Variation of emissions by emitting sector in the "Green Growth" Scenario in the Amazon and Cerrado — Brazil — annual from 2021 to 2040 (Gg of CO_2eq).

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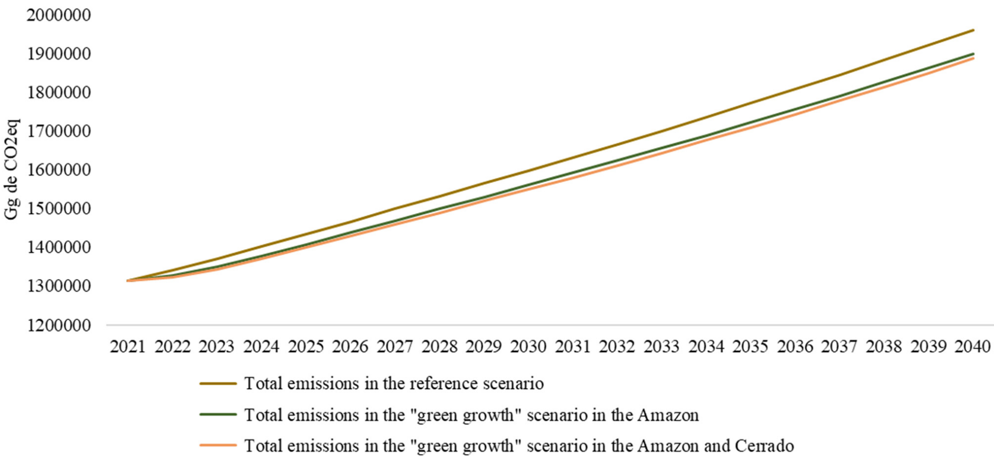
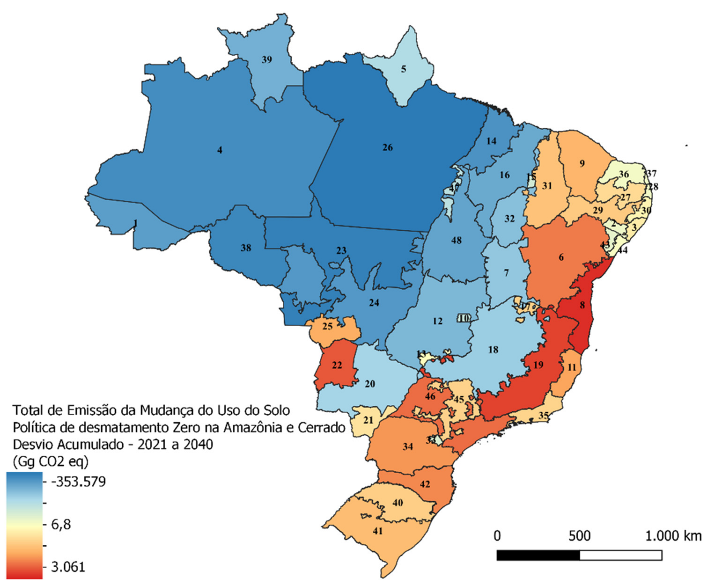


Source: Own elaboration based on simulation results with the BLUME model.
*Green Growth = zero deforestation plus sectoral investments.

Graph 11. Variation of total emissions in the Reference Scenario, "Green Growth" Scenario in the Amazon and Cerrado and "Green Growth" Scenario in the Amazon — annual from 2021 to 2040 (Gg of CO_2eq).



Source: Own elaboration based on simulation results with the BLUME model.
*Green Growth = zero deforestation plus sectoral investments.

Figure 3. Variation of regional emissions of the LULUCF sector in the "Green Growth" Scenario in the Amazon and Cerrado — (accumulated deviation % in relation to the Reference Scenario) (Gg of CO_2eq).

comply with the INDC emissions target (2015) for the year 2030 which is 1,493,443 Gg of CO_2eq. However, the 2025 target, which is to reduce emissions to a total of 1,650,648 Gg of CO_2eq, would be achieved.

In regional terms, there is an increase in emissions from the LULUCF sector in regions that are not part of the Amazon and Cerrado biome, especially in the Atlantic Forest regions. The map in Fig. 3 below shows the regional emissions in the cumulative deviation for the period from 2021 to 2040, that is, the variation in emissions from the "Green Growth" scenario in the Amazon and Cerrado in relation to the Reference Scenario. The regions in blue would be responsible for reducing emissions, the more intense the blue the greater the region's contribution to the fall in emissions from the LULUCF sector. The regions in red would indicate an increase in emissions, the more intense the red, the greater the emissions. Thus, the BA_Mata Atlantica and MG_Mata Atlantica regions would present the greatest increase in emissions compared to the Reference Scenario and the PA_Amazônia region would present the greatest drop in emissions.

4. Conclusion

The main objective of this research was to analyze the economic and environmental impacts of "Green Growth" scenarios in the main Brazilian biomes. In these scenarios, in addition to eliminating deforestation for productive purposes, investments in the agriculture and livestock sectors were incorporated in order to simulate economic growth with forest preservation.Therefore, it sought to contribute to the agenda of the impacts of mitigation policies adopted by Brazil. To this end, a dynamic interregional Computable General Equilibrium (CGE) model called BLUME was built. This model incorporates a land use and integrated emissions module, capable of capturing the processes of direct and indirect land use changes (LUC and ILUC) and projecting emissions not only from land use changes, but also from other issuing sectors. Thus, this work also contributes methodologically by integrating land use changes with the total emissions of the economy per Brazilian biome, in addition to considering regional heterogeneity at the environmental and land use levels.

The first simulated scenario, called the reference scenario, projects the growth of the economy in a business-as-usual situation, without policies to restrict land use or mitigate emissions. In this scenario, the results indicated that the BA_Cerrado and MT_Amazônia regions would have the highest GDP growth in the period, driven mainly by the increase of soybean and cattle production. In this case, deforestation of 57 Mha is projected from 2021 to 2040 with the highest growth of pasture areas. Deforestation in the Amazon biome would be 18 Mha, with the largest area lost in the PA_Amazônia region, and in the Cerrado biome would be 20 Mha, with emphasis on the MT_Cerrado region.

The results seem to indicate an indirect effect of soybean and livestock on deforestation through an LUC and ILUC process of soil transition. Soybean production

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would pressure the displacement of cattle production to new forest areas. Emissions from the land use change and alteration sector (LULUCF) would reach 5,008,217 Gg of CO_2eq in the accumulated period and the total emissions, considering the other issuing sectors, would be 32,441,933 Gg of CO_2eq.

In the policy simulation, in addition to zero deforestation in the Amazon and Cerrado, an additional 1.3% would be invested in the agricultural sectors. This investment is equivalent in the model to a total of BRL 542 billion in 20 years, BRL 127 billion of which in the Amazon (BRL 6.4 billion per year) and BRL 415 billion in the Cerrado (BRL 20.8 billion per year). This amount is equivalent to 1.6% of the region's GDP per year during this period. Comparatively, the Northern Region Development Fund (FNO) alone disbursed BRL 10.3 billion to the Amazon agricultural sectors in 2021.

This amount would be enough to neutralize the negative impacts of the zero-deforestation policy, in addition to bringing economic benefits. This policy would generate a GDP increase of 1.5% in the period, if compared to the Reference Scenario. The same policy for the Amazon biome alone would generate a national GDP growth of 0.4%. The accumulated deforestation in the country would be 21 Mha, 63% less than in the Reference Scenario. For comparison, if the policy were applied only in the Amazon biome, the reduction of deforestation would be 31%. The increase in pasture areas would be 10 Mha, 41% less than in the Reference Scenario. Even with the significant decrease in productive areas, the agricultural sectors would still show growth in their activities, with the exception, once again, of the livestock sectors. These would need larger investments to offset the losses from the land restriction policy.

In environmental terms, the policy would reduce emissions from the LULUCF sector by 20% compared to the baseline scenario. In other words, there would be a reduction in 983.632 Gg de CO_2eq. If we consider the simulated investment of BRL 542 billion over 20 years as a cost of noncarbon emissions, we would have a value of BRL 551,019 per Gg of CO_2eq or BRL 511 per ton of CO_2eq. It is worth remembering

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Table 8. Summary of key results.

Variables	Reference scenario (1)	"Green growth" Amazon (2)	"Green growth" Amazon and Cerrado (3)	Variation between (1) and (3) (%)
National GDP (annual average)	2%	2.01%	2.03%	1.5%
Accumulated deforested area (Mha)	57	39	21	−63.2%
Accumulated pasture area (Mha)	37.1	21	10	−73.0%
Accumulated crop area (Mha)	17.4	15	10	−42.5%
Accumulated LULUCF sector emissions (Gg de CO_2eq)	5,008,217	4,250,388	4,024,585	−19.6%
Accumulated total emissions (Gg de CO_2eq)	32,441,933	31,688,505	31,485,251	−2.9%

Source: Own elaboration based on simulation results with the BLUME model.

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that the simulated investment would not only avoid 20% of the emissions from the LULUC sector but would promote economic growth of 1.5% of the national GDP. If compared with a "Green Growth" scenario only in the Amazon biome, the drop in emissions would have a difference of 5% between the scenarios, however, with lower GDP growth. Table 8 contains the main results for the different scenarios, for comparison purposes.

Overall, the results indicate that simulated policies would be able to avoid part of national emissions and still promote economic growth. With the implementation of investments, the agricultural sectors would not only compensate for the economic loss of the land restriction policy, but would also present productive growth, with the exception of the livestock sectors. These sectors proved to be highly sensitive to deforestation control policies. This is because the greater the dependence of the sector or region on the factor of land production and the greater the participation of land remuneration on GDP, the greater the impact of policies involving changes in land use.

Therefore, these regions and sectors would need different investments and economic stimuli to be able to reconcile economic growth and environmental conservation. According to Stabile *et al.* (2020), targeted investments aimed at increasing productivity in medium and large farms, especially in livestock, would be sufficient to achieve Brazil's agricultural development goals, without new deforestation. The economic benefits of intensifying meat production on medium and large farms outweigh the investments required for this. Technical assistance is also important to improve the economic, social and environmental results of small-family cropland, since small farmers occupy a large area of the Amazon.

In addition, the results indicate that with the simulated policies, Brazil would reach the emissions target defined during COP21 for 2025, and would get very close to reaching the 2030 targets. The latter would be easily achieved with the mitigation policies of other sectors, such as the ABC+ Plan programs for the agricultural sector. To achieve these goals, it is important that policies contain illegal deforestation by eliminating land grabbing and land speculation, as well as reducing legal deforestation on private property. It is estimated that about 28 Mha of Amazonian forests on private properties could be legally deforested according to existing legislation (Stabile *et al.*, 2020). One way to avoid this deforestation would be through environmental compensation and payment for environmental services such as REDDs.[13]

It is worth noting that the costs measured in this paper are based on the loss that the zero-deforestation policy would cause on the GDP of the regions, therefore, it does not consider the institutional expenses for the implementation of policies among other administrative values. Therefore, the costs presented here should not be interpreted as the final amount necessary for the implementation of the policies, but rather as an

[13]REDD+ is an incentive developed under the United Nations Framework Convention on Climate Change (UNFCCC) to financially reward developing countries for their results in Reducing Greenhouse Gas Emissions from Deforestation and Forest.

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estimate of the direct investment necessary to promote economic growth with lower environmental impacts.

These investments can be related, although without a precise correlation based on the methodology used, to technological improvements such as biotechnology, nanotechnology and genetic engineering techniques, opening space for the bioeconomy in Brazil. In addition to investments in fixed assets such as machinery, equipment and agricultural products (tractors, harvesters, irrigation pivots, fertilizers and pesticides) and planting systems (conventional, direct planting system, integrated systems). These investments could be financed by programs such as the Amazon Fund, the National Climate Change Fund (FNMC), the ABC+ Plan or even part of the public investments of the "Harvest Plan" could be redirected to increase agricultural and livestock productivity, as recommended in Stabile *et al.* (2020).

Finally, it is important to highlight some shortcomings of the model and suggestions for future research. Due to the interdisciplinary nature of the topic, the harmonization of economic and environmental databases is still a limitation. This makes the model incapable of detailing the Earth system with great precision, limiting analyses involving more specific land use categories and deforestation resulting from urban growth. In addition, there is difficulty in assigning values to vacant lands, which would improve the accuracy of forest land income and the impacts of the simulations.

ORCID

Géssica C. P. Souza https://orcid.org/0000-0002-9247-9180
Edson Paulo Domingues https://orcid.org/0000-0002-7640-6010
Aline Magalhães https://orcid.org/0000-0003-3349-5372

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